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USER'S GUIDE TO BIODYN-80: AN INTERACTIVE SOFTWARE PACKAGE FOR --ETC(U)

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USER'S GUIDE TO BIODYN-80; AN INTERACTIVE SOFTWARE PACKAGE FOR MODELING BIODYNAMIC FEEDTHROUGH TO A PILOT'S HANDS, HEAD, AND EYES

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NOTICES

TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-81-59

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

HENNING E. VON GIERKE
Director
Biodynamics and Bioengineering Division
Air Force Aerospace Medical Research Laboratory

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This is the User's Manual for BIODYN-80, an interactive computer program for solving the dynamic motion response of seated aircrew (pilots or equipment operators) working in a biodynamic environment (such as vibration or changing levels of acceleration in aircraft, surface vehicles, or motion simulators). The multi-degree-of-freedom, lumped-parameter model includes elements for: pelvis, torso, neck, head, eyes, upper and lower arms, hand-grip and control stick (center-stick with arm rest). An active 21-parameter neuromuscular system is operable with either the limb or head control. The eye's image

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20. ABSTRACT (continued)

motion dynamics include a 13-parameter model for the fixation and vestibulo-ocular reflexes. The nonlinear equations of motion of the body's main elements are linearized about a general set of body-limb-head postures, ranging from prone, to erect, to supine. Inputs are vertical or fore-aft accelerations of the seat, while a wide variety of outputs are available, including motions of the shoulder, head, eyes, arm, hand, or control stick. Typical parameter ranges and sources are given, along with two "typical" sets: a seated-pilot with center-stick, and a seated crewman with hands in lap.

The program can be run in a mode interactive with the user, or in a batch mode. The program helps the user load the necessary parameters, and offers a "quick-look" printer plot of the resulting frequency responses, in standard Bode-plot forms. The program also can produce biomechanical transmissability files needed for use in the Air Force's PIVIB program for tracking performance estimation.

Procedures and examples are given for both a Cyber 175 version available on "INTERCOM" for Wright-Patterson Air Force Base users, and a PDP-10 version, available on the Tymshare national computer network for other users.

PREFACE

This report was prepared by Systems Technology, Inc., Hawthorne, California, under Contract F33615-79-C-0519, for the Air Force Aerospace Medical Research Laboratory (AFAMRL). Mr. Charles Harmon, Biodynamic Effects Branch of the Biodynamics and Bioengineering Division, served as the technical monitor for AFAMRL in support of Project 2312-V3-20, "Man-Machine Interface Model."

TABLE OF CONTENTS

		Page
INTRODUCTION		4
A	Scope	4
B	Background	4
C	Applications	5
SOFTWARE OVERVIEW		6
MODEL DESCRIPTION		10
A	Biomechanical Model	10
B	Limb Neuromuscular Model	12
C	Neck/Head/Eye Models	12
USING BIODYN-80		17
A	CREATE	17
B	BIODYN	27
C	Plot	28
D	Interface with PIVIB	28
E	For Assistance	35
APPENDIX A	DEFINITION OF PARAMETERS, SYMBOLS, RANGES AND TYPICAL VALUES	36
APPENDIX B	DEFINITION OF FORCING FUNCTION AND RESPONSE VARIABLES	45
APPENDIX C	EQUATIONS OF MOTION	49
APPENDIX D	TYMSHARE EXAMPLE PROBLEM	57
APPENDIX E	INTERCOM EXAMPLE PROBLEM	66
REFERENCES		69

LIST OF ILLUSTRATIONS

Figure		Page
1	Overview of BIODYN-80	7
2	BIODYN-80 Flow Chart	8
3	Main Biomechanical Elements	11
4	Linearized Limb Neuromuscular System	13
5	Simplified Head Pointing Neuromuscular System	14
6	Block Diagram for Head, Eye, Vestibular Models and Display Kinematics	15
7	Example Long Format File Listing	20
8	Example Short Format PARAMETER File Listing	22
9	Format for BIODYN-80 Transfer Function Printouts	29
10	Format Used for BIODYN-80 TAPE19 File of Transfer Functions	30
11	Example Output from Plot	31
12	BIODYN-80 Transfer Functions Which May Be Used as PIVIB Input	34

LIST OF TABLES

Table		
1	Parameter and Symbol Definitions, Ranges, and Typical Values	36
2	Parameter File Structure (Short Format)	43
3	Input (Forcing Function) Variables	45
4	Output (Response) Variables	46

INTRODUCTION

A. SCOPE

BIODYN-80 is a versatile computational tool used to determine transmissibilities (transfer functions) between vertical and/or fore-aft vibrational inputs and important biodynamic outputs, such as motions of the torso, head, eyes, arms or hands. The program scenario assumes a seated pilot, gripping an arbitrary-angle stick and viewing a display, possibly engaged in a tracking task. The physical model uses an "isomorphic," (lumped parameter,) approach to represent the relevant portions of the whole-body torso, limbs and head, as well as postural compliances among the joints. The implementation of this model includes a chain of interacting parallel and serial second-order elements, with neuromuscular and other force feedbacks at the arm or head. The resulting equations are in "second-order element" matrix form and apply to a wide range of seated postures. A separate input file, which describes the particular set of parameters to be used, is created by the user (usually by modifying one of a cataloged set). This file is incorporated in the matrix to produce linearized coefficients for perturbations about the selected equilibrium posture. A variety of outputs and inputs can be specified to evaluate the desired transmissibility transfer functions, and these are written to a file in formatted form for plotting or use in other programs. On-line, printer-drawn frequency response plots (Bode format) are available to aid in interactive user-computer operations, or to screen significant results from batch runs.

B. BACKGROUND

BIODYN-80 is one result of a several year small-scale development effort, reported in detail in References 1-6. It is based on vibration

measurements made at the Aerospace Medical Research Lab/Biodynamics Division (AMRL/BB) and elsewhere. Most of the torso, limb and stick model elements are based on independent vibration measurements (e.g., Reference 5), and the neck, head and eye effects show promising correlations with the few available measurements on image motion effects (Reference 6). However, many aspects remain to be explored, validated or upgraded as more experiments are run and interpreted via BIODYN-80.

C. APPLICATIONS

The possible applications of this program are many. It should be used in the early stages of experimental design for determining the optimal locations for vibration measurements and/or selection of frequencies. It can also be used by development engineers for solving practical pilot-vehicle interface design problems such as pilot-induced oscillations and for optimizing design alternatives such as seat location, orientation and suspension parameters. Flight control system designers can make use of BIODYN-80 output in optimizing vehicle/ aircrew ride qualities and visual performance effects, possibly incorporating anti-vibration devices to improve the design.

One further application of BIODYN-80 deserves special mention. Its vibration-input to biodynamic parameter-output transfer functions are ideally suited as input to PIVIB, another software package which relates pilot tracking performance to the vibration environment (Reference 7). PIVIB accepts biomechanical transfer functions in the format created by BIODYN-80. The details of the BIODYN-80/PIVIB interface will be found in a later section.

The remainder of this report details the use of BIODYN-80, and describes the model and the equations comprising it. Detailed instructions for the creation of the required input files, and a complete example problem are also included.

SOFTWARE OVERVIEW

Figure 1 is a functional block diagram description of the elements in BIODYN and its interface with PIVIB. The BIODYN-80 package is composed of three programs. The first, called CREATE,* interactively sets up the two input files used by BIODYN. The second program called BIODYN, is the actual "number cruncher," which structures and solves the biomechanical equations and computes the desired transfer functions. The third program called PLOT, accepts the file of BIODYN transfer functions, prints selected ones in a form readily comprehended by the user, and prepares "quick plot" Bode plots on the line printer, to facilitate a visual interpretation of the transfer function information. Both BIODYN and PLOT are designed primarily as batch programs while, CREATE permits conversational user interaction in structuring input data.

A subsequent link in this series of programs is PIVIB. It is a large batch program with three modules. The first, BDMOD, computes the response behavior of the various biomechanical subsystems. The second, PVMOD, uses the results of BDMOD and the BBN optimal control model to estimate pilot tracking performance within the vibration environment. The final module, VEXEC, provides the top level communication interface between BDMOD and PVMOD, and performs no actual computation. The BDMOD module expects biodynamic transfer functions in a format generated by BIODYN. Only the relationships of BIODYN-80 to PIVIB are described herein, because PIVIB is run separately and has its own User's Manual (Reference 7).

Figure 2 presents a flow chart covering the use of BIODYN and PIVIB in a given session. The detailed description of the various steps for BIODYN is found in Section D. Note that the flow of execution can be

---

*The CREATE program should not be confused with INTERCOM's EDITOR subcommand CREATE; it has been given the permanent file name EXECRT to distinguish it from the latter.

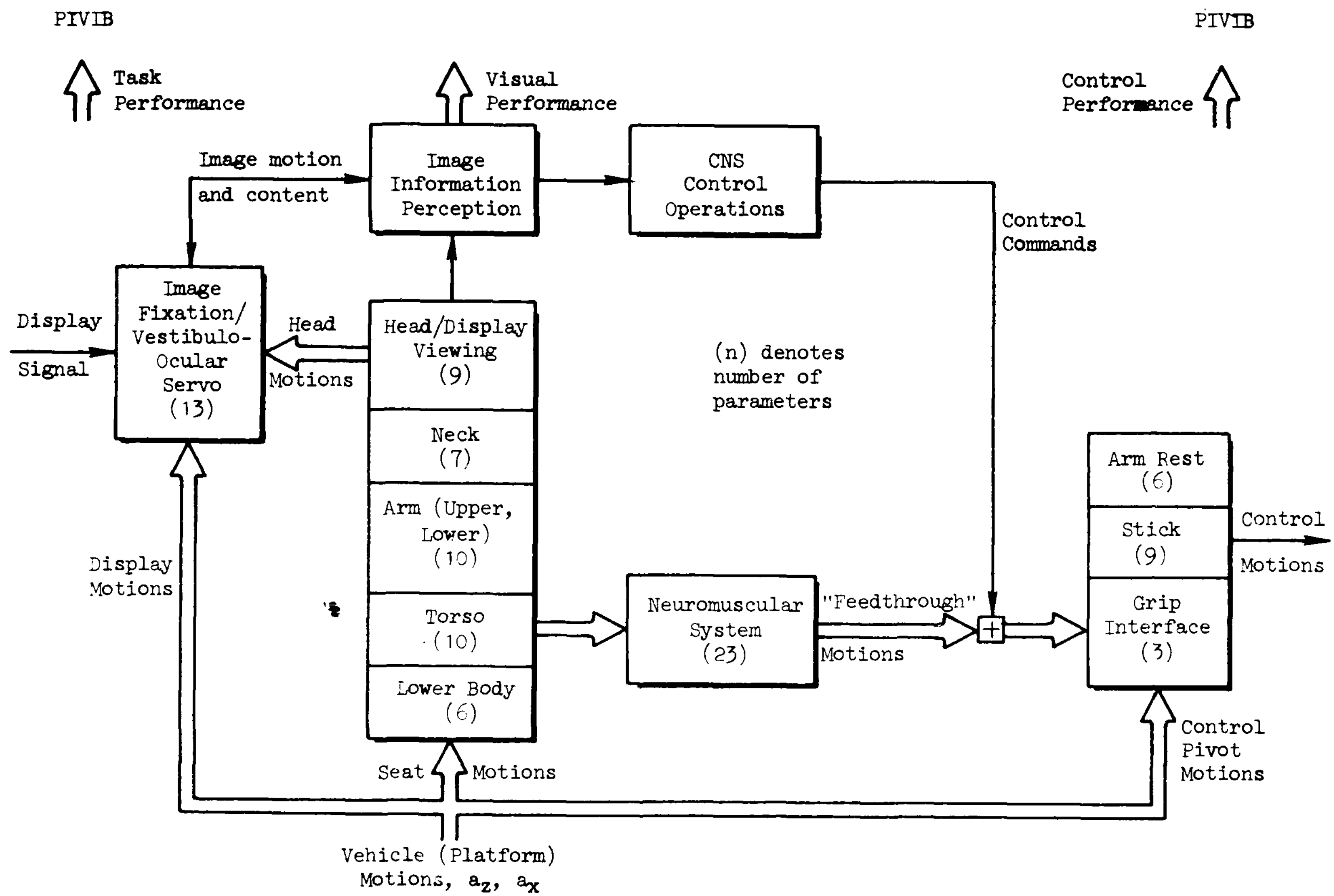


Figure 1 Overview of BIODYN-80

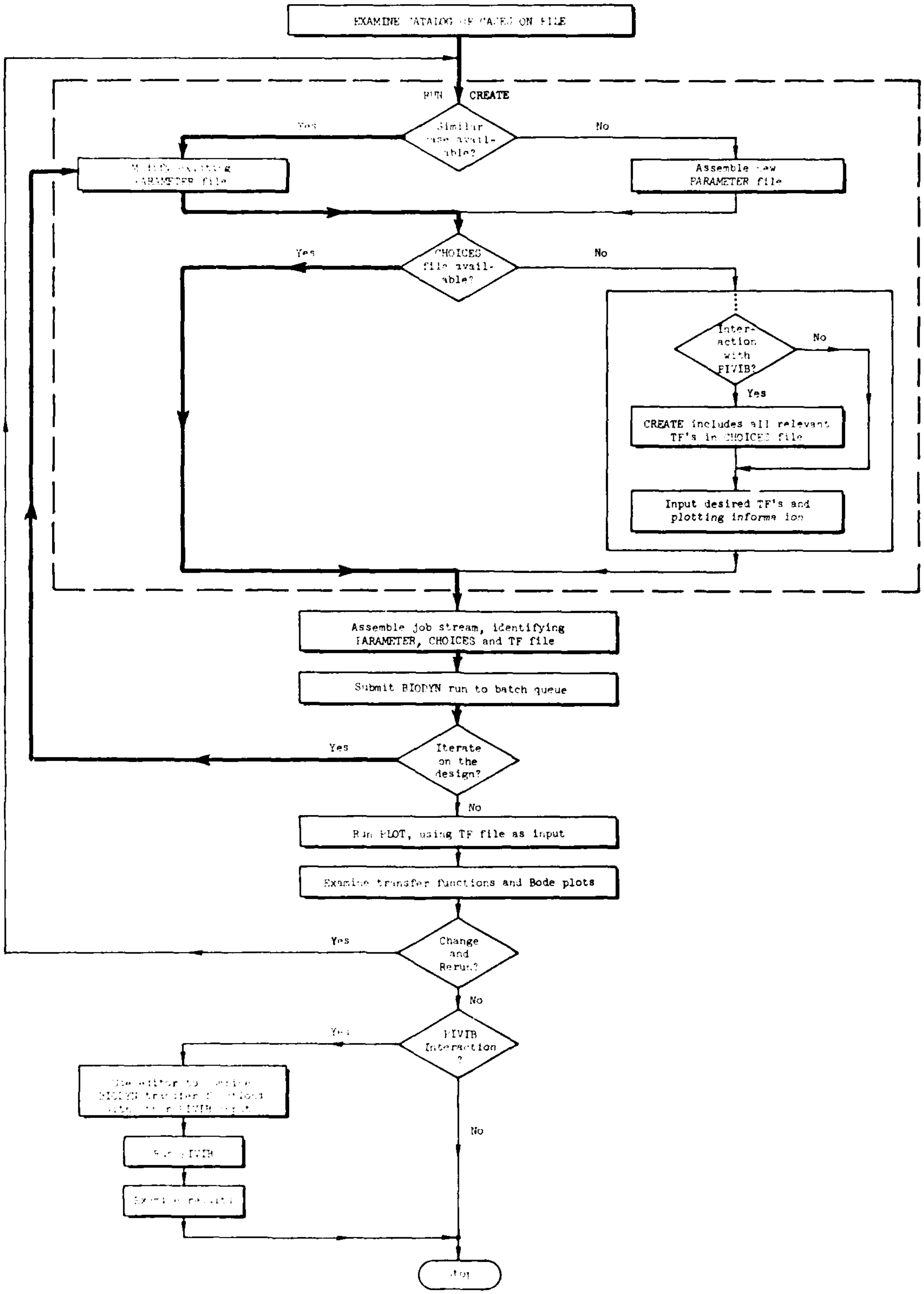


Figure 2 BIODYN-80 Flow Chart

used to solve a single problem, by submitting a single batch request, or to iterate on a design by submitting a number of batch requests using the same CHOICES file and slightly altered PARAMETER files (heavy lines in Figure 2).

BIODYN-80 uses three separate files in performing its computations. The PARAMETER file contains the set of 96 parameters used to define the specific pilot/posture/display/vibration characteristics. Appendix A contains a complete description of each parameter, including definition, mnemonic, nominal value, recommended range of values and reference (where available). CREATE is used to assemble this file and can modify an existing file or produce an entirely new file. The CHOICES file contains the list of desired transfer functions to be computed and output by BIODYN, as well as directives for producing the line printer Bode plots. Again, this CHOICES file is assembled by CREATE. Finally, the TF file is used to store the resulting transfer functions output by BIODYN, and is read by the PLOT routine for generating Bode plots.

PIVIB employs a single large file to direct its flow of execution. This file defines the vibration environment, biomechanical transfer functions, tracking dynamics, tracking performance requirements, and pilot limitations (bandwidths, time delays, etc.). Currently, this file is assembled in the editor, using output from BIODYN-80 if desired.

BIODYN-80 and each of its predecessors were developed on the Tymshare, Inc., PDP-10 computers. BIODYN-80 has been adapted to the CDC "Intercom" System on the CDC 6600 or CYBER 175 at WPAFB in order to increase its availability to Air Force users, and to interact with PIVIB, which is also operable on the WPAFB CDC computer. The details of this manual will address its use on the CDC machine; an example of a Tymshare session is given in Appendix D. Throughout the manual, however, it is assumed that the user is familiar with the WPAFB CYBER 175, and in particular has experience with the INTERCOM operating system. If not, the user should read References 8 and 9 first.

MODEL DESCRIPTION

Three distinct subsystem models are included in BIODYN-80. They are described individually below.

A. BIOMECHANICAL MODEL

Figure 3 (updated from Figure 2 of Reference 3) presents the biomechanical model and defines many of the necessary parameters that describe the nominal (or trim) situation. It utilizes an "isomorphic," or body-mimicking representation, of the major body segments in their orientations, simplified to a minimum number of lumped parameter equivalents. The biomechanical features include:

- Semisupine torso; sliding hip plus rocking chest supported on a compliant buttocks/seat.
- Head bobbing on an articulated neck with passive compliance, or active neuromuscular system.
- Upper arm and forearm links plus grip-interface compliance, driven by an active neuromuscular system.
- Arm-rest restraints (optional).
- Stick "feel system" dynamics from zero to infinite stiffness, and any angle of stick or grip.

The simplified torso model was derived to describe the dominant motions of the head and arm elements; the "pin joint" node between upper and lower torso segments is not meant to represent any physical feature. In practice, the masses and inertias are obtained from tabulated biomechanical and anthropometric data for the appropriate sized person (e.g., Reference 11), the postural angles are based on the actual situation (preferably via a side-view photo), and the spring forces and damping coefficients are fitted to data or taken from other sources (e.g., References 3 and 12).

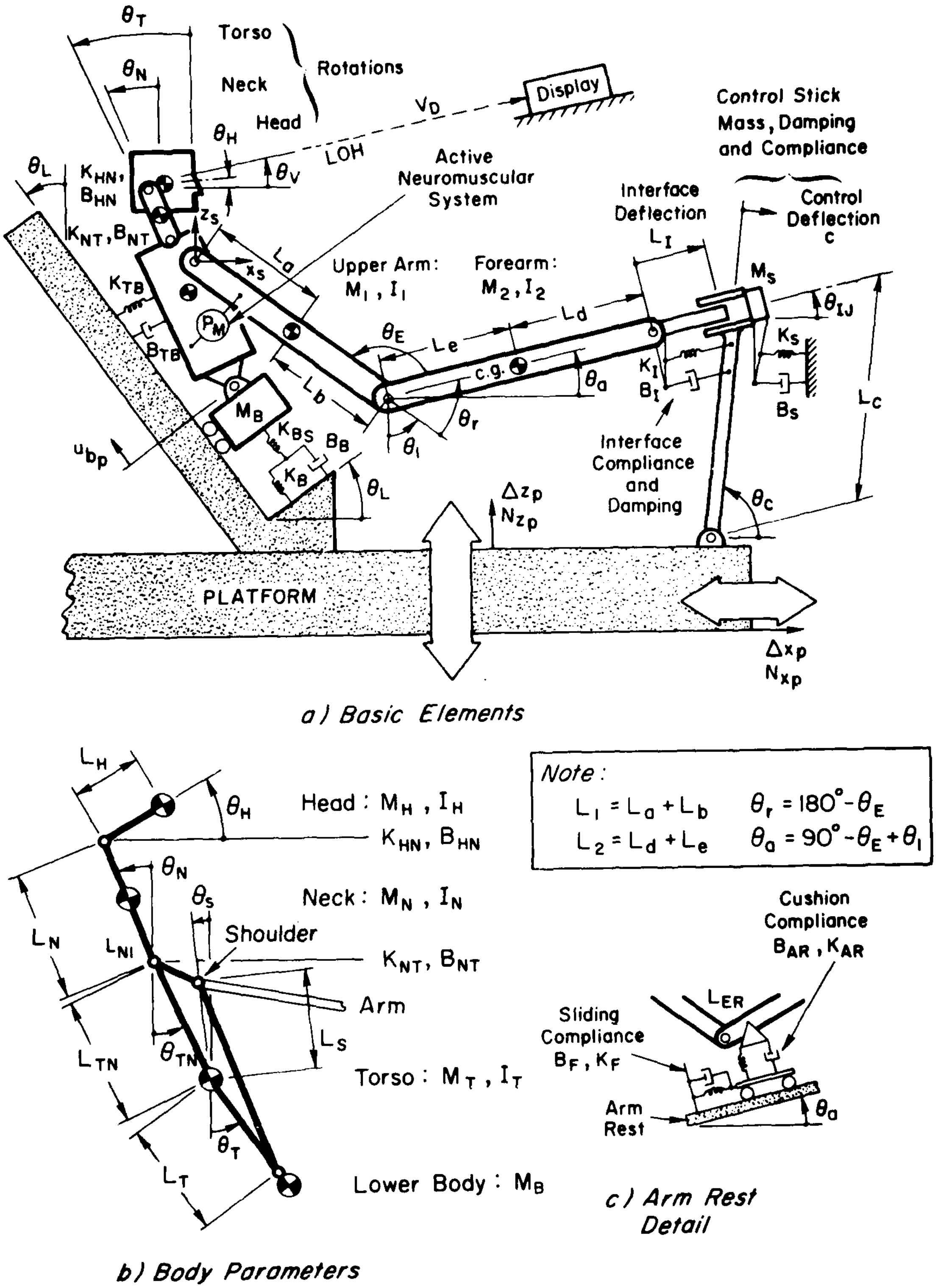


Figure 3 Main Biomechanical Elements

B. LIMB NEUROMUSCULAR MODEL

The active neuromuscular system noted on Figure 3 is a schematic representation of the net effect of complex agonist/antagonist muscle pairs controlling the upper arm or head based on the work summarized in Reference 10. An "NM switch" is defined in the PARAMETER file which causes this neuromuscular model to control the limb (NM = 0) or the head (NM = 1). A linearized representation of the limb neuromuscular model is shown in Figure 4, while the head neuromuscular model is depicted in Figure 5. This model relates the action of the muscle pairs to the effective (spindle) sensors of muscle length and force as well as proprioception from the stick grip interface (in the case of the limb neuromuscular model) or the head-neck interface (in the case of the head neuromuscular model), thus closing the receptor-CNS-effector loop.

Unless neuromuscular properties are being investigated, it is recommended that the typical values of the parameters shown in Table A-1 be used. These are representative of a normal person's arm-hand or head-neck system, and generally yield reasonably damped neuromuscular servo properties. The neuromuscular parameters listed in Appendix A are characteristic of the largest muscles in the body (e.g., the legs), but experience has shown that the dynamic properties (torque/inertia ratios, damping ratios, natural frequencies, etc.) are about the same for all postural muscle pairs. Here, an empirical scale factor S (> 1.0) is used to scale the normalized muscle to a particular configuration, as though the muscle acted normal to the upper arm c.g. A more detailed description of the neuromuscular model is found in Reference 10.

C. NECK/HEAD/EYE MODELS

Figure 6 illustrates the basic elements involved in the neck/head/eye model. Details involving validation and example use of this subsystem model are found in Reference 6. The task is to keep the eye fixated on the target, i.e., null the relative eye (point of regard) deviation (RED) at the display. The moving base can produce image error disturbances, both from induced head rotation and translation as well as

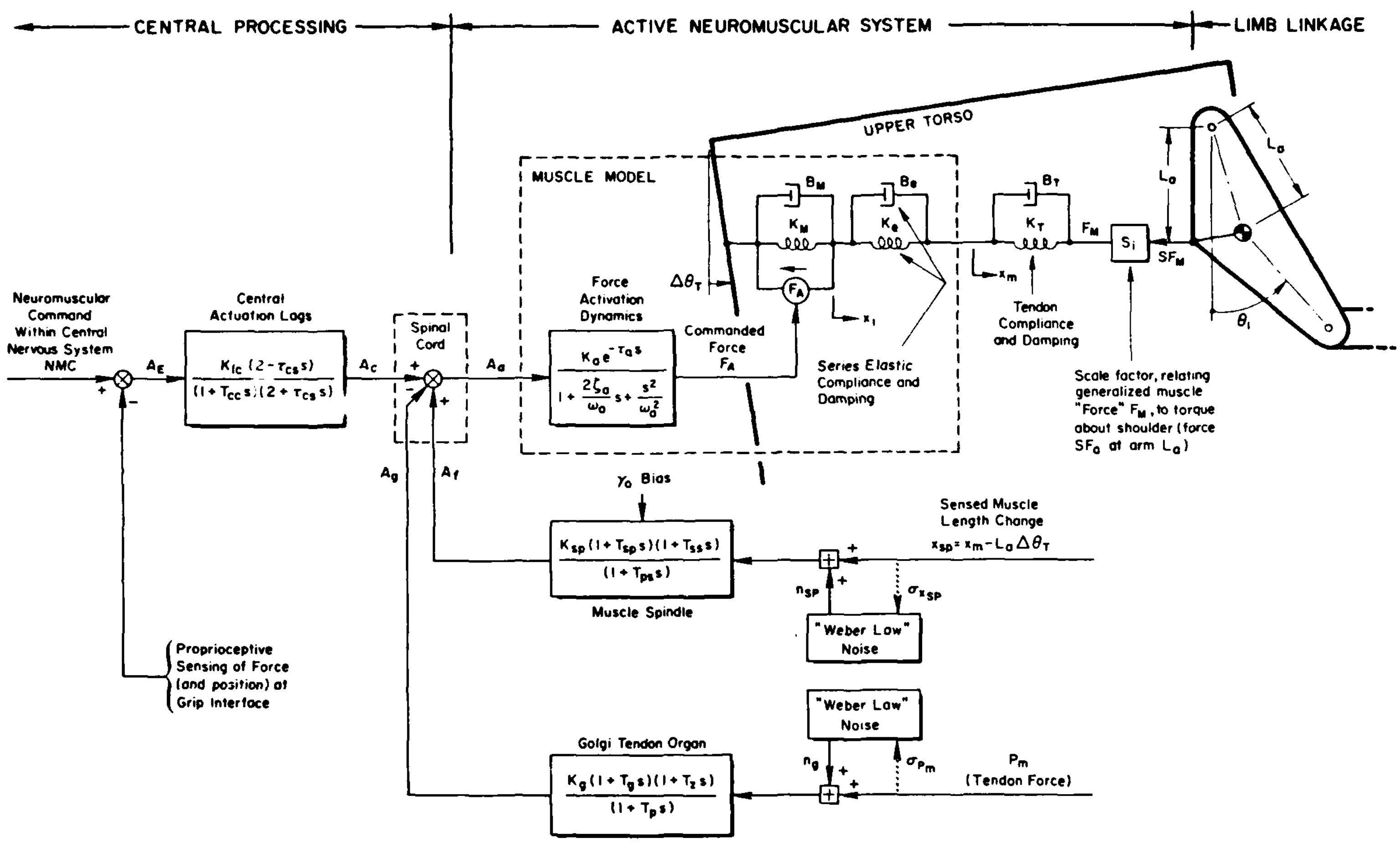
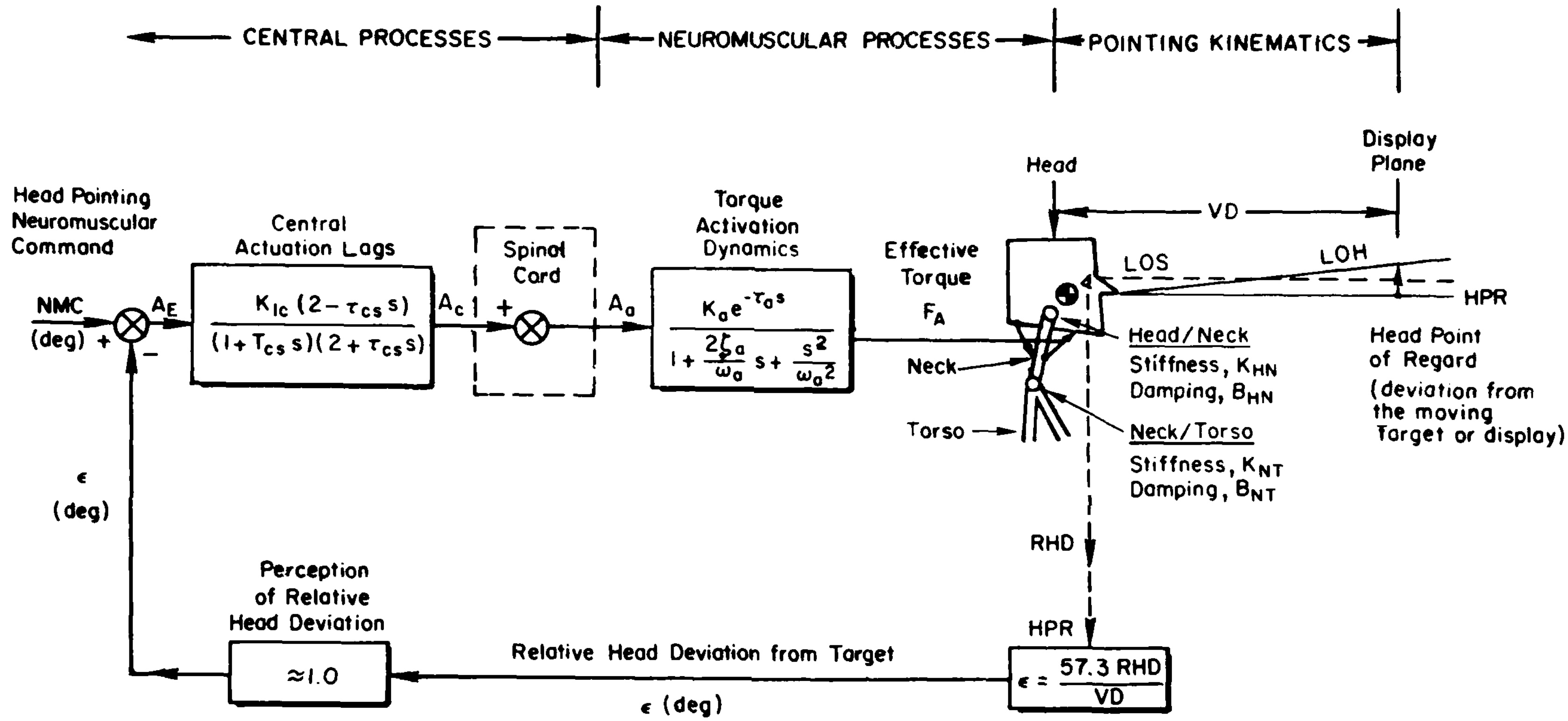


Figure 4 Linearized Limb Neuromuscular System (When the Option NM = 0)



Notes:

When NM=1, this simplified NM system is connected to the head to maintain head pointing at the vibrating target. The values of the parameters F_A, K_{IC}, K_a, etc. are different between the limb case (NM = 0) and head case (NM = 1)

Figure 5 Simplified Head Pointing Neuromuscular System
(When Option NM = 1)

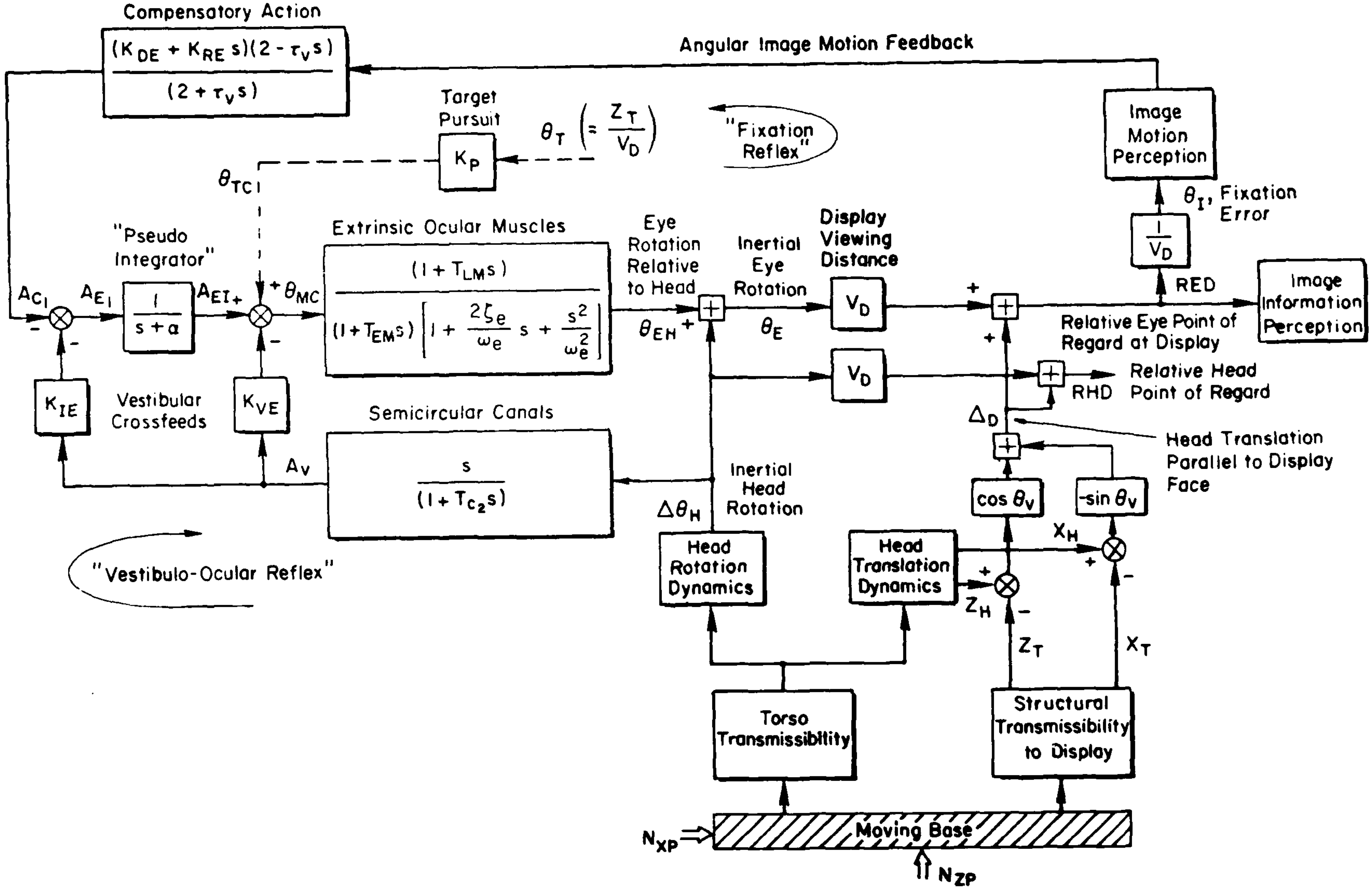


Figure 6 Block Diagram for Head, Eye, Vestibular Models and Display Kinematics

target motions. The "vestibulo-ocular reflex" is a "crossfeed" (or "feedforward") that rotates the eye oppositely to the head to compensate for head rotation, i.e., to maintain approximate inertial eye fixation.

The "Fixation Reflex" or feedback tracking loop involves the subject's efforts to null the image error θ_I by compensatory eye movements. The "Target Pursuit" path (shown dashed) models the subject's "feedforward" operations on the perceived absolute target motions in inertial space (as distinct from the image error motions). For highly predictable and perceivable target motions the Target Pursuit path is capable of greatly reducing the image errors, but it is not involved in most vibration cases because of insufficient bandwidth.

The linearized model formulation assumes that the target remains within the foveal area (3-4 deg field), and that angular velocities are small (i.e., less than 20 deg/sec.) such that saccades are rare and can be ignored. Additionally, the vibration-induced motions will always be small enough to permit linearization of all angular functions and allow a quasi-linear representation of the dynamic elements about each "operating point" (posture, view geometry, frequency). The operating point angles can have any values within human limits for a seated pilot or crewman.

The three subsystem models described above contain parameters which must be assigned values via the PARAMETER file, in order to describe the desired problem to BIODYN. These parameters are defined in Appendix A. The available input (forcing function) variables and output (response) variables are given in Appendix B. Two different input deflection variables are available for the x and z axes. BZP and BXP should be used when absolute ouputs (referenced to inertial space) are desired; DZP and DXP are used when outputs relative to the moving platform are desired. The equations of motion are in Appendix C. Background on their derivation and development are given in a series of prior reports (References 1-3, 6, 10).

USING BIODYN-80

Three job steps are required for a complete run of BIODYN-80. The CREATE program is used interactively via a remote terminal, to assemble the PARAMETER and CHOICES files. These files are then read by BIODYN and the transfer functions computed, stored on the TF file, and listed at a line printer. The TF file is in turn read by the PLOT program to produce any Bode plots desired. Each of these steps is described in detail. Note that all user interaction with the computer assumes the user is logged in to CDC's INTERCOM. It is assumed that the user has access to Intercom set "AFML" where the program and its files reside. For other setname groups, please consult your Computer Center Representative to get on the AFML list, or for instructions on how to use a "modified job stream listing" (Reference 8).

A. CREATE

Because of the large number of parameters required by BIODYN-80, it was decided that a dedicated interactive "editor" for creating parameter files was needed to produce rational, error-free input files, and thereby avoid aborting during the subsequent, and expensive, batch run of BIODYN (for example, due to a missing decimal point). Furthermore, this approach allows the maintenance of a "catalog" of PARAMETER files for various postures and situations, from which the most appropriate one can be easily selected and modified for a particular situation. The CREATE program serves in this regard by allowing a user to interactively assemble new parameter files or modify existing ones. CREATE also performs various data checks and identifies common parameter entry errors. This section details the use of the CREATE program.

1. Entering CREATE

CREATE makes use of five files, as defined by the PROGRAM card:

TAPE4 = INPUT file (the user's terminal)

TAPE5 = OUTPUT file (the user's terminal)

TAPE7 = CHOICES file (if new one is created)

TAPE8 = PARAMETER file (new or modified)

TAPE20 = PARAMETER file (existing)

The PROGRAM card automatically assigns the INPUT and OUTPUT files to the appropriate tape units. If an existing PARAMETER file is to be accessed, it must be assigned prior to executing CREATE. The job stream to be input by the user looks like this (detailed examples are given later, in Appendices D and E):

REQUEST,TAPE7,*PF REQUEST,TAPE8,*PF ATTACH,TAPE20,pfn_1 ATTACH,EXECRT EXECRT	(pfn_1 is the PARAMETER file name selected by the user from the permanent file catalog within the setname AFML group)

Now the user is at the entry level of CREATE. The first issue addressed is creating the PARAMETER file, or modifying an existing PARAMETER file. The computer's first prompt

NEW FILE?

asks the user to identify which option is desired. Answers are YES or NO; any other response will cause the query to be repeated.

2. Modifying a PARAMETER File

If the answer is NO, the values stored on the file assigned to TAPE20 are read. The user may list those values by responding to the next prompt

LISTING DESIRED?

with YES. A NO response will skip over the listing option. Any other response will cause repeat of the question. The listing produced can either be long or short. The long listing provides parameter definition, mnemonic, units and current value, while the short listing prints only values, grouped according to each element (see Table A-2, Appendix A). Examples of each are given in Figures 7 and 8, respectively.

Response to the prompt:

```
(LO)NG OR (SH)ORT LISTING?
```

determines which listing to generate. A response other than LO or SH will cause repeat of the question.

Values are now ready for change, as indicated by the message:

```
INPUT MNEMONIC (5 CHARS) AND VALUE FOR EACH CHANGE,
TO EXIT, TYPE XXX.
```

To change any desired parameter value, its mnemonic from the second column of the definitions in Appendix A is input. Mnemonic must be left justified within a 5 character field followed by a comma, followed by the new value. The mnemonic is then checked against the internal list of permissible mnemonics; e.g., if ABDCE is not found, the message:

```
MNEMONIC ABCDE NOT PERMISSIBLE.  PLEASE REINPUT.
```

appears and the user should try again. Likely errors include typos, and forgetting to pad the 5 character field with trailing blanks.

Once a correct mnemonic is identified, its new value is compared with the recommended range of values for that parameter. If the value is not within that range, a warning message appears:

```
WARNING - RECOMMENDED RANGE FOR THIS PARAMETER IS
        0.5 TO 3.5 GS
DO YOU WANT TO CHANGE THE VALUE?
```

STD CREWMAN, HANDS ON KNEES

PARAMETER DEFINITION	MNEMONIC	UNITS	VALUE
LOWER BODY MASS	XMB	KG	14.0000
L. BODY SEAT CUSHION DAMPER	BB	N/M/S	315.000
L. BODY SEAT CUSHION STIFFNESS	XKB	N/M	49360.0
SERIES SPRING GRAD.-LOWER BODY	GK1	N/M	119320.
SEAT TILT ANGLE	THL	DEG	13.0000
TRIM VERTICAL ACCEL.	G	M/S2	9.80000
TORSO MASS	XMT	KG	18.0000
TORSO INERTIA	ZIT	KGM2	.800000
TORSO DAMPING	BTB	NM/R/S	40.0000
TORSO STIFFNESS	XKTB	NM/R	500.000
ANGLE OF XLT FROM VERTICAL	THT	DEG	-15.0000
TORSO CG TO HIPS PIVOT LENGTH	XLT	M	.150000
ANGLE OF XLTN	THTN	DEG	-5.00000
TORSO CG TO NECK/TORSO PIVOT	XLTN	M	.300000
ANGLE OF XLS	THS	DEG	-5.00000
TORSO CG TO SHOULDER LENGTH	XLS	M	.300000
NECK MASS	XMN	KG	1.24000
NECK INERTIA	ZIN	KGM2	.240000E-02
NECK/TORSO DAMPER	BNT	NM/R/S	.100000
NECK/TORSO STIFFNESS	XKNT	NM/R	50.0000
ANGLE OF XLN	THN	DEG	-30.0000
NECK LENGTH	XLN	M	.124440
NECK CG TO NECK/TORSO PIVOT	XLN1	M	.622200E-01
HEAD MASS	XMH	KG	3.10000
HEAD INERTIA	ZIH	KGM2	.303000E-01
HEAD/NECK DAMPER	BHN	NM/R/S	.126000
HEAD/NECK STIFFNESS	XKHN	NM/R	15.0000
HEAD/NECK COMPLIANCE	CH	-	1.00000
ANGLE OF XLH	TH	DEG	60.0000
HEAD CG TO HEAD/NECK PIVOT LEN	XLH	M	.250000E-01
LINE OF SIGHT ANGLE	THV	DEG	-30.0000
VIEWING DISTANCE	VD	M	.685300
UPPER ARM MASS	XM1	KG	1.37200
UPPER ARM INERTIA	Z1	KGM2	.120000E-01
UPPER ARM ANGLE	T1	DEG	15.0000
UPPER ARM LENGTH	D1	M	.290000
UPPER ARM CG	R1	M/M	.440000
LOWER ARM MASS	XM2	KG	1.01700
LOWER ARM INERTIA	Z2	KGM2	.152000E-01
ELBOW ANGLE	TE	DEG	115.000
LOWER ARM LENGTH	D2	M	.305000
LOWER ARM CG	R2	M/M	.500000
GRIP INTERFACE ANGLE	TIJ	DEG	0.
GRIP INTERFACE TIME CONSTANT	TIF	S	.100000
GRIP INTERFACE COMPLIANCE	CI	M/N	1.00000

(continued)

Figure 7 Example Long Format File Listing

STICK MASS	XMS	KG	4.00000
STICK DAMPER	BS	N/M/S	240.000
STICK GRADIENT	XKS	N/M	10000.0
[illegible] PARAMETER	CKS	—	1.00000
[illegible] SENSITIVITY TO NX	SX	N/G	0.
[illegible] SENSITIVITY TO NZ	SZ	N/G	0.
[illegible]	THC	DEG	90.0000
[illegible]	XLC	M	.550000
[illegible] SCALE FACTOR	XKSC	/M	.100000E-0
[illegible] DAMPER (NORMAL)	BAR	N/M/S	0.
[illegible] STIFFNESS (NORMAL)	XKAR	N/M	0.
[illegible] DAMPER (TANG)	BAT	N/M/S	0.
[illegible] STIFFNESS (TANG)	XKAT	N/M	0.
[illegible] ARM REST DISTANCE	XLER	M	0.
[illegible] ARM [illegible] ON ARM REST	ARMR	—	0.
[illegible] FOR [illegible] AND F.A.D.	NM	—	0.
[illegible] FOR MUSCLE ELEMENTS	SI	—	50.0000
[illegible]	TCC	S	.909000E-01
[illegible] DELAY	TCS	S	.890000E-01
[illegible]	XKAA	N/N	1.00000
[illegible] F.A.D.	ZA	—	.800000
[illegible] FREQUENCY IN F.A.D.	WA	R/S	16.0000
[illegible] IN F.A.D.	TAA	S	0.
[illegible] DAMPER	BM	N/M/S	1.00000
[illegible] SYSTEM	XKM	N/M	2.00000
[illegible] ELEMENT DAMPER	BE	N/M/S	2.43000
[illegible] ELEMENT GRAD	XKE	N/M	40.0000
[illegible]	BT	N/M/S	0.
[illegible]	XKT	N/M	80.0000
[illegible] GAIN	XKSP	N/M	5.00000
[illegible] TIME CONSTANT	TSP	S	.909000E-01
[illegible] TIME CONSTANT	TPS	S	0.
[illegible] I.C.	TSS	S	0.
[illegible]	XKG	N/N	.500000
[illegible] TIME CONSTANT	TG	S	.550000E-01
[illegible] TIME CONST	TZ	S	0.
[illegible] CONSTANT	TP	S	0.
[illegible]	XKDE	R/R	7.07950
[illegible]	XKRE	R/R/S	0.
[illegible] ION LOOP	TV	S	.450000E-01
[illegible] FREQ	ALPHA	R/S	.300000
[illegible]	XKP	R/S	0.
[illegible] SENSR	XKIE	—	.670000
[illegible] SENSR	XKVE	—	.100000
	TC2	S	.100000E-01
[illegible]	TEM	S	.100000
[illegible]	TLM	S	.125000E-01
[illegible] MODE	QE	—	1.00000
[illegible]	ZE	—	.650000
[illegible]	WE	R/S	316.230

Figure 7 (Concluded)

```
PARAMETERS FOR:

SEATED CREWMAN - VIEWING DISTANCE = 9 CM

LOWER BODY
 14.000       315.00       49360.       .11932E+06  13.000       9.8000
TORSO
 18.000       .80000       40.000       500.00
-15.000       .15000      -5.0000       .30000     -5.0000       .30000
NECK
 1.2400       .24000E-02  .10000        50.000
-30.000       .12444      .62220E-01
HEAD/DISPLAY VIEWING
 3.1000       .30300E-01  .12600        15.000      1.0000
 60.000       .25000E-01 -30.000        .90000E-01
ARM (UPPER, LOWER)
 1.3720       .12000E-01  15.000        .29000      .44000
 1.0170       .15200E-01  115.00        .30500      .50000
GRIP INTERFACE
0.            .10000      1.0000
STICK
 4.0000       240.00      10000.        1.0000      0.           0.
 90.000       .55000      .10000E-01
ARM REST
0.           0.           0.            0.          0.           0.
NEUROMUSCULAR SYSTEM
  0  50.000
 .20000E-01  .90900E-01  .89000E-01
 1.0000       .80000      16.000       0.
 1.0000       2.0000      2.4300        40.000      0.           80.000
 5.0000       .90900E-01 0.            0.
 .50000       .55000E-01 0.            0.
IMAGE FIXATION/VESTIBULO-OCULAR SERVO
 7.0795      0.           .45000E-01   .30000      0.
 .67000       .10000      .10000E-01
 .10000       .12500E-01  1.0000        .65000      316.23
```

Figure 8 Example Short Format PARAMETER File Listing

If a mistake has been made in typing the new value, a YES answer will allow retyping of both the mnemonic and its corrected value. If, however, the value is correct, even if out of range, a NO answer will cause the value to be stored as it stands. Any response other than YES or NO will cause the warning message to be repeated.

The range of parameters given in Appendix A is as wide as can be allowed for typical applications of BIODYN-80 (e.g., arm joint limits). Values outside this range are used at the user's risk, and precise postural angles for the given case should be carefully checked at this point. (It is good practice to check your lengths and angles by drawing a stick figure to scale, using the desired values.)

When all the desired changes have been made, an input of XXX causes control to leave the modify mode. An opportunity to change the case title is then presented as

```
TITLE IS STD CREWMAN, HANDS ON KNEES
CHANGE DESIRED?
```

A YES answer causes the message

```
NEW TITLE:
```

to appear and a new title (60 characters maximum) can be typed. A NO response skips this section; other responses cause the prompt to repeat.

After all desired changes have been made, the user is once again given the opportunity to list the file, using either the LOng or SHort format, as described above. At this point the computer writes the new values to the PARAMETER output file, TAPE8.

3. Assembling a New PARAMETER File

If most of the parameters are new, then instead of modifying an existing file the initial prompt

```
NEW FILE?
```

is answered YES. Every parameter value must then be input. The message

```
INPUT VALUE FOR EACH MNEMONIC. FOR FURTHER EXPLANATION, TYPE?
```

initiates this process. For each parameter, the mnemonic is printed as, for example, Viewing Distance, VD:

```
VD =
```

and the value is accepted in floating point format. If the user is uncertain as to the range of appropriate values, an expanded prompt may be requested by typing "?". The expanded prompt for VD is, for example:

```
VD = ?

VD VIEWING DISTANCE
RECOMMENDED RANGE = 0.5 TO 3.0 M
VD =
```

the user can then enter the desired value.

As each value is read, it is checked against the recommended range of values, in order to weed out input errors due to wrong sign or incorrect decimal placement. If the value is not within range, the warning message given previously appears. The user always has the option of modifying or saving any value typed.

This process continues until all 26 parameters have been entered. The case title is then added as a response to

```
INPUT TITLE FOR THIS CASE:
```

At this point, a LOng or SHort format listing may be generated as discussed above. The file is then written by the computer to the PARAMETER file designated TAPE8.

4. Assembling the CHOICES File

The next section of CREATE is used to assemble a new CHOICES file which specifies the transfer functions to be output. Note that there is no provision for modifying an existing CHOICES file; any changes to an existing CHOICES file must be made by creating an entirely new file. The prompt

```
NEW CHOICES FILE?
```

has two responses: a NO allows the user to skip this entire section if an existing CHOICES file will be used as input to BIODYN; a YES response will cause prompting for the CHOICES file components as described below. Any other response will cause the prompt to be repeated.

A YES response to the next prompt

```
BIODYN TFS DESIRED FOR PIVIB?
```

will automatically generate the ten transfer functions to be included in the PIVIB input file. This is mandatory if interaction with PIVIB is anticipated. The response and forcing function variables involved are shown later, in Figure 12. A NO answer skips this section; other answers cause repeat of the question.

All other desired transfer functions are entered by the user in response to the following computer-specified format:

```
TRANSFER FUNCTION INPUT:
FIRST LINE - RESPONSE MNEMONIC, FORCING FUNCTION MNEMONIC
    (AAA, AAA); ENTER XXX TO STOP
SECOND LINE - PLOTTING INFORMATION, 5 ITEMS:
    BODE LOWER FREQ. LIMIT
    BODE UPPER FREQ. LIMIT
    BODE UPPER PHASE LIMIT (0. DEFAULTS TO 200.)
    BODE LOWER PHASE LIMIT (0. DEFAULTS TO -400.)
    LIST (1. TO LIST TABLE, 0. FOR NO LIST)
IF NO PLOT DESIRED, ENTER 0. FOR ALL ITEMS
```

Note that the parameters for each transfer function are entered on two consecutive lines, each item separated by a comma, each line followed by CR.

The mnemonics requested are three-character codes as defined in Appendix B. The program checks each mnemonic against the list of acceptable codes. If a match is not made, the error message

XYZ NOT PERMISSIBLE, PLEASE REINPUT.

is given and the entire first line must be retyped.

If Bode plots are desired, the frequency and phase limits must be entered; if not, zeros are assumed. The frequency limits must bound a frequency range of no more than 3 decades. If frequencies with an unacceptable range are entered, the message

```
MAX FREQUENCY RANGE IS 3 DECADES
PLEASE REINPUT ENTIRE LINE
```

appears and, all five items for that transfer function must be re-typed. The phase limits are unbounded, but entering zeros will cause default to +200.0 deg and -400.0 deg for the upper and lower limits, respectively. If a tabular listing, including frequency, amplitude, and phase at 20 increments/decade intervals is desired, a 1.0 should be entered as the fifth item; otherwise enter 0.0.

The *CREATE* program stops when an XXX is read in the CHOICES file section. The two files created must be saved as permanent files by giving the following INTERCOM commands:

CATALOG,TAPE7,pfn_2,RP=10
CATALOG,TAPE8,pfn_3,RP=10

where pfn_2 is a new (seven character) permanent file name assigned to the CHOICES file and *pfn_3 is a new (seven character)* permanent file name assigned to the PARAMETER file. The user is now ready to exercise BIODYN.

The user can interactively create a number of PARAMETER and CHOICES files, each uniquely named for subsequent use in the BIODYN program. In

most cases one same set of transfer function choices will be adequate for a variety of different parameter sets.

B. BIODYN

Because of memory size limitations presently imposed by the INTERCOM operating system, BIODYN must be run in the batch mode. A batch job can be submitted through INTERCOM using the following command sequence

```
EDITOR
CREATE,S
ABC,CM150000,STCSA.
ATTACH,TAPE7,pfn2.          User supplies desired
ATTACH,TAPE8,pfn3.          file name for each pfn
REQUEST,TAPE19,*PF.
ATTACH,EXEBIO.
EXEBIO(TAPE4,OUTPUT,TAPE7,TAPE8,TAPE19,TAPE21).
CATALOG,TAPE19,pfn4,RP=999.
*EOR
SAVE,GOBIO,NOSEQ
END
COMMAND = BATCH,GOBIO,INPUT,HERE
```

The first section of this batch request assigns the PARAMETER and CHOICES files produced by CREATE to the tape units which BIODYN reads. The BIODYN program is then retrieved and executed.

BIODYN first reads the PARAMETER file and uses it to set up the equations in the form

$$Ax = Bu$$

where x is a vector of response variables (currently dimensioned 48) and u is a vector of forcing function variables (dimensioned 9). The desired transfer functions (as listed in the CHOICES file) are then evaluated, using Cramer's rule and several advanced factorization algorithms in order to obtain the first- and second-order poles and zeros. These are all written to a file called TAPE19 (the TF file), as well as to the line printer (via the OUTPUT file). The format used by the program for

printing the transfer functions is shown in Figure 9, while the format for storing these transfer functions on TAPE19 is given in Figure 10.

The TF file (TAPE19) is used by the PLOT program for generating the quick-look Bode plots on the line printer. Thus, the last lines supplied by the user in the batch job stream "rewind" this file and assign it a permanent file name pfn_4.

C. PLOT

The Bode plots, if desired, may be generated at the user's terminal or written to a local file for later examination, as the user wishes. The user's job stream looks like the following:

```
ATTACH,TAPE19,pfn4.        pfn4 is the file name of
ATTACH,EXEPLT.             the plot instructions
EXEPLT(OUTPUT,TAPE19)
```

The output from this routine consists of four items. First, the input file mnemonics are printed, so the user can identify which plots are forthcoming. Then, for each transfer function, three items are printed. The transfer function dipoles (first and second order) which have been cancelled are first, followed by the numerator and denominator of the transfer function. Then, the Bode plot is "drawn." Finally, if a listing was requested in the CHOICES file, it follows the Bode plot. An annotated example is given in Figures 11a, b, and c.

D. INTERFACE WITH PIVIB

Ten of the possible BIODYN-80 transfer functions can be used as input to PIVIB. These are listed in Figure 12. The input file structure for PIVIB is quite lengthy and complex, involving over 200 parameters. An explanation of it is beyond the scope of this user's manual, and the interested reader is referred to Reference 7, the PIVIB User's Manual. A brief outline of the steps used to generate the PIVIB input file is given below.

Each transfer function is to be interpreted as

$$\text{Transfer Function} \equiv \frac{N^{\text{output}}_{\text{input}}}{\Delta}(s) = \frac{\kappa\left\{\Pi\left(s + \frac{1}{T_z}\right)\right\}\cdot\left\{\Pi\left(s^2 + 2\zeta_z\omega_z s + \omega^2\right)\right\}}{\left\{\Pi\left(s + \frac{1}{T_p}\right)\cdot\left\{\Pi\left(s^2 + 2\zeta_p\omega_p s + \omega^2\right)\right\}\right.}$$

where Π denotes a product of first- or second-order roots, and κ is the so-called "root locus gain" (of the high-frequency asymptote):

$$\kappa = \frac{\text{High Frequency Gain of Numerator}}{\text{High Frequency Gain of Denominator}}$$

and the various first- and second-order poles and zeros are indicated below. The transfer function can also be interpreted in Bode format, as:

$$\text{Transfer Function} \equiv \frac{\kappa\left\{\Pi\left(T_z s + 1\right)\right\}\cdot\left\{\Pi\left(\frac{s^2}{\omega_z^2} + \frac{2\zeta_z s}{\omega_z} + 1\right)\right\}}{\left\{\Pi\left(T_p s + 1\right)\right\}\cdot\left\{\Pi\left(\frac{s^2}{\omega_p^2} + \frac{2\zeta_p s}{\omega_p} + 1\right)\right\}}$$

where K_{OL} is the gain of the low-frequency asymptote ("Bode gain"):

$$K_{OL} = \frac{\text{Low Frequency Gain of Numerator}}{\text{Low Frequency Gain of Denominator}}$$

```
                 11-MAR-80    17:06  <------------------------------ Date, Time

  CASE:HEAD,NECK,TORSO  ONLY  <------------------------------------- Case Identifier

                                                                     TRANSFER FUNCTION COMPONENTS:
DENOMINATOR:  ------------------------------------------------------ High-frequency gain
                                                                     (denominator) Kp
   .10464E-12
  ( 46.384      )  ( 100.00      )  ( 530.63     ) <---------------- First-order poles (1/T)
  (( .44231      , 8.3929      , 3.7123      , 7.5273      ))
  (( .42607      , 10.483      , 4.4663      , 9.4835      ))        Second-order poles
  (( .13854      , 17.112      , 2.1996      , 16.970      ))
  (( .97453E-01, 32.746      , 3.1912      , 32.590      ))  <------ ((ζ, ω, ζω, ω√(1 - ζ²)))
  (( .11386      , 44.530      , 5.0704      , 44.241      ))                  Re    Im
  (( .65021      , 316.83      , 206.02      , 240.70      ))
   .12459E+12  ------------------------------------------------------ Low-frequency gain (denominator)

                 ---------------------------------------------------- Numerator: output/input
NUMERATOR:  KHO/DZF  ------------------------------------------------ <High-freq. gain> numerator alone Kz1
  -.83639E-11     -79.934  <---------------------------------------- <<High-freq. gain>> for transfer function
  ( .00000      )  ( .00000      )  ( 46.384      )  ( 100.00      )                        K = Kz/Kp
  ( 534.59      )                                                <-- First-order zeros
  (( .44231      , 8.3929      , 3.7123      , 7.5273      ))
  (( .67357      , 17.729      , 11.942      , 13.104      ))
  ((-.35676      , 35.405      ,-12.631      , 33.075      ))  <---- Second-order zeros
  (( .29926      , 44.192      , 13.225      , 42.166      ))
  (( .65024      , 316.83      , 206.02      , 240.70      ))
   -.11284E+12      -.90565     >>  <------------------------------- <<Low-freq. gain, transfer function>>
                 ---------------------------------------------------- <Low-freq. gain, numerator alone>
```

Figure 9 Format for BIODYN-80 Transfer Function Printouts

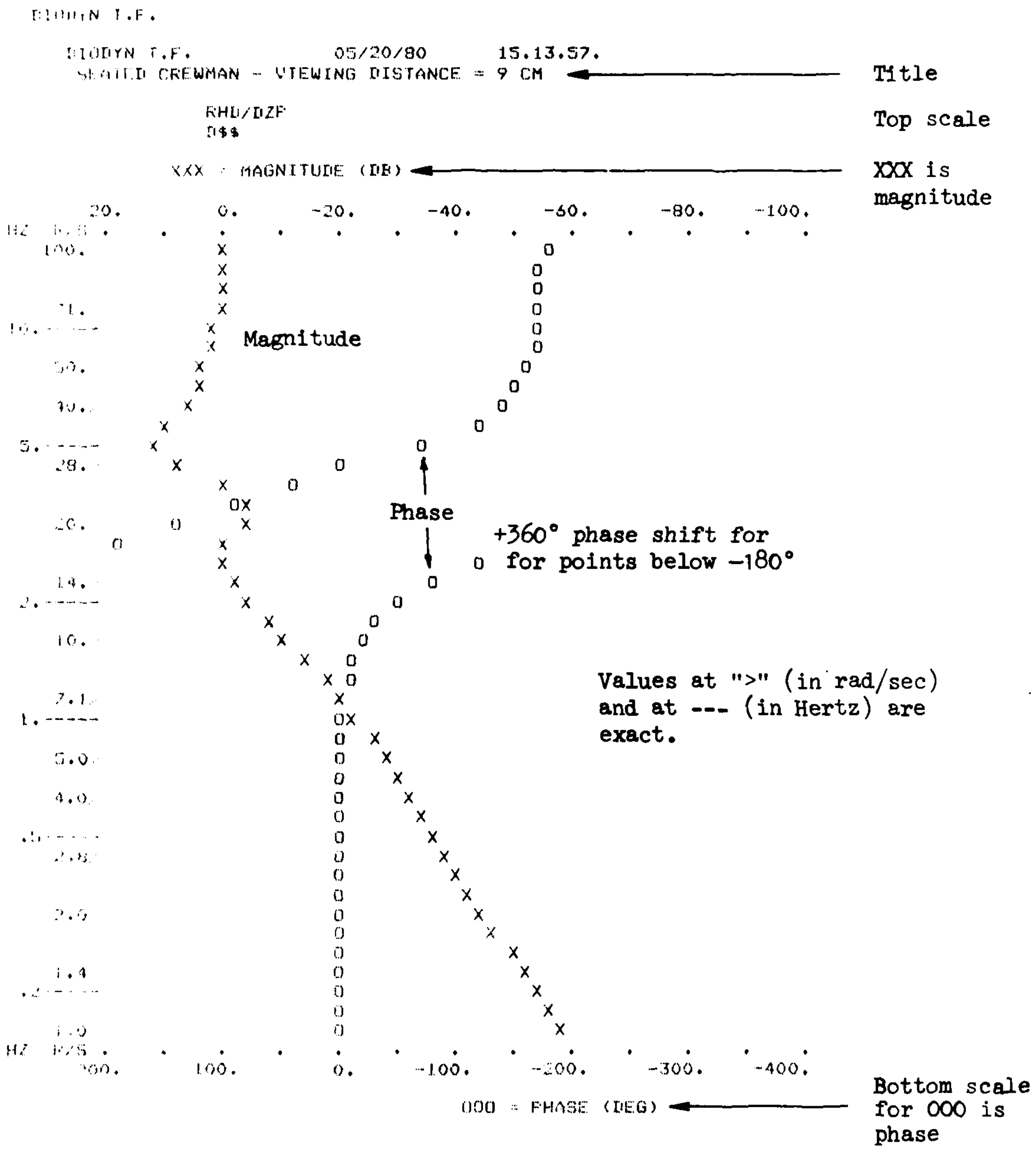
Format	Comment
Case title (15A4)	
D$$	(Specifies denominator)
NP1, NP2, K_p, 0., 0., 0., 0., 0.	(2I4, G14.6, 5F7.1)
$1/T_{p_1}$	
$1/T_{p_2}$	First-order poles (5X, G14.6)
.	
.	
.	
$\zeta_{p_1}, \omega_{p_1}$	Second-order poles (ζ_1, ω_1)
$\zeta_{p_2}, \omega_{p_2}$	(5X, 2F14.6)
.	
.	
.	
XXX/XXX	First transfer function numerator
NZ1, NZ2, K_z, WI, WF, XU, XL, XP	(2I4, G14.6, 5F7.1)
$1/T_{z_1}$	
$1/T_{z_2}$	First-order zeros (5X, G14.6)
.	
.	
.	
$\zeta_{z_1}, \omega_{z_1}$	
$\zeta_{z_2}, \omega_{z_2}$	Second-order zeros (ζ_2, ω_2)
.	(5X, 2G14.6)
.	
.	
XXX/XXX	Second transfer function numerator
	.
	.
	.

where

NP1 = No. first-order poles	K_z = High-frequency numerator gain
NP2 = No. second-order poles	WI = Bode plot lower frequency limit
K_p = High-frequency denominator gain	WF = Bode plot upper frequency limit
NZ1 = No. first-order zeros	XU = Bode plot upper phase limit
NZ2 = No. second-order zeros	XL = Bode plot lower phase limit
	XP = Listing switch

Figure 10. Format Used for BIODYN-80 TAPE19 File of Transfer Functions

```
   BIODYN T.F.              05/20/80       15.13.57.
    SEATED CREWMAN - VIEWING DISTANCE = 9 CM              Title

   D$$
   RHD/DZP                                                Dump of file

BIODYN T.F.

   BIODYN T.F.              05/20/80       15.13.57.
    SEATED CREWMAN - VIEWING DISTANCE = 9 CM              Title

               RHD/DZP  <-------------------------------- First transfer
               D$$                                        function
FIRST-ORDER DIPOLES CANCELLED :
 46.384000
 100.00000                                                Cancelled dipoles
                                                          (only exact can-
SECOND-ORDER DIPOLES CANCELLED :                          cellation
 .44230900     , 8.3929300
 .60022000     , 50.002500
 .65024400     , 316.83100

NUMERATOR:
                                                          High frequency gain
-.81361
(0.         )  (0.         )  ( 10.955     )  ( 11.950     )  First-order zeros
( 22.500    )  ( 107.75    )  ( 535.79     )
(( .22639     , 8.4561     , 1.9144     , 8.2365     ))
(( .78552     , 13.624     , 10.702     , 8.4311     ))
(( .82761     , 20.272     , 16.777     , 11.379     ))   Second-order zeros
((-.16669     , 21.651     ,-3.6090     , 21.348     ))
(( .22759     , 47.017     , 10.700     , 45.783     ))

DENOMINATOR:

( 10.957    )  ( 11.983    )  ( 22.499     )  ( 107.81     )  First-order poles
( 531.02    )
(( .22869     , 8.4682     , 1.9366     , 8.2437     ))
(( .40550     , 13.701     , 5.5558     , 12.524     ))
(( .24026     , 16.682     , 4.0081     , 16.193     ))
(( .82362     , 20.305     , 16.723     , 11.516     ))   Second-order poles
(( .94299E-01, 31.293     , 2.9509     , 31.153     ))
(( .19289     , 46.973     , 9.0608     , 46.091     ))
  -.13857E-02  <----------------------------------------- Low frequency gain
```



b) **Printer-Generated Frequency Response (Bode Plot)**

Figure 11 (Continued)

STODYN T.F.

STODYN T.F. 05/20/80 15.13.57. **Title**

SEATED CREWMAN - VIEWING DISTANCE - [illegible]

[illegible]

[illegible]

W	DB	DEG
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	360.9
[illegible]	-55.07	360.5
[illegible]	-51.0[illegible]	360.6
.08	-49.[illegible]	360.6
[illegible]	-46.[illegible]	360.7
[illegible]	-44.[illegible]	360.7
[illegible]	-42.[illegible]	360.8
[illegible]	-40.7[illegible]	360.8
[illegible]	-38.[illegible]	360.9
[illegible]	-36.33	[illegible]
[illegible]	-34.5[illegible]	360.8
[illegible]	-32.13	360.6
[illegible]	-29.7[illegible]	360.4
[illegible]	-27.38	359.9
[illegible]	-25.16	359.1
[illegible]	-22.65	357.8
[illegible]	-19.94	355.7
[illegible]	-17.10	352.6
[illegible]	-1[illegible].02	347.5
[illegible]	-1[illegible].7[illegible]	339.0
[illegible]	-7.38	325.8
[illegible]	-[illegible].17	306.2
[illegible]	-[illegible].19	278.1
[illegible]	-.[illegible]	240.0
[illegible]	[illegible]	194.0
[illegible]	-[illegible].12	143.1
[illegible]	-1.16	86.4
[illegible]	[illegible]	39.6
[illegible]	7.[illegible]	-.4
[illegible]	1[illegible].37	-46.2
[illegible]	[illegible].10	-119.6
[illegible]	6.08	-139.9
[illegible]	5.00	-152.3
[illegible]	[illegible].06	-163.0
[illegible]	[illegible].10	-168.9
[illegible]	1.05	-171.5
[illegible]	.34	-172.9
[illegible]	-.15	-173.9
[illegible]	-.51	-174.7
[illegible]	-.78	-175.4

Listing of frequency (rad/sec), amplitude (dB) and phase (deg) at 20 evenly-spaced increments/decade. (This listing is only generated if XL = 1.0 in the CHOICES file for this transfer function)

c) Listing of Frequency Response Values

Figure 11 (Concluded)

Note: $\not{b}$ denotes a typed blank space.

Output	BIODYN TF		PIVIB TF		
Shoulder: (S)	$\frac{\not{b}XS}{BXP}$	=	$\left.\frac{Ch1}{Ch1}\right\|_S$	=	$\frac{\text{Inertial horizontal shoulder deflection}}{\text{Horizontal platform deflection}}$
	$\frac{\not{b}XS}{BZP}$	=	$\left.\frac{Ch1}{Ch2}\right\|_S$	=	$\frac{\text{Inertial horizontal shoulder deflection}}{\text{Vertical platform deflection}}$
	$\frac{\not{b}Z1}{BXP}$	=	$\left.\frac{Ch3}{Ch1}\right\|_S$	=	$\frac{\text{Inertial vertical shoulder deflection}}{\text{Horizontal platform deflection}}$
	$\frac{\not{b}Z1}{BZP}$	=	$\left.\frac{Ch3}{CH2}\right\|_S$	=	$\frac{\text{Inertial vertical shoulder deflection}}{\text{Vertical platform deflection}}$
Head: (H)	$\frac{DTH}{BXP}$	=	$\left.\frac{Ch3}{Ch1}\right\|_H$	=	$\frac{\text{Inertial head pitch}}{\text{Horizontal platform deflection}}$
	$\frac{DTH}{BZP}$	=	$\left.\frac{Ch3}{Ch2}\right\|_H$	=	$\frac{\text{Inertial head pitch}}{\text{Vertical platform deflection}}$
	$\frac{DZH}{BXP}$	=	$\left.\frac{Ch2}{Ch1}\right\|_H$	=	$\frac{\text{Inertial vertical head deflection}}{\text{Horizontal platform deflection}}$
	$\frac{DZH}{BZP}$	=	$\left.\frac{Ch2}{Ch2}\right\|_H$	=	$\frac{\text{Inertial vertical head deflection}}{\text{Vertical platform deflection}}$
Stick (C)	$\frac{\not{b}C\not{b}}{DXP}$	=	$\left.\frac{Ch1}{Ch1}\right\|_C$	=	$\frac{\text{Longitudinal stick deflection}}{\text{Horizontal platform deflection}}$
	$\frac{\not{b}C\not{b}}{DZP}$	=	$\left.\frac{Ch1}{Ch2}\right\|_C$	=	$\frac{\text{Longitudinal stick deflection}}{\text{Vertical platform deflection}}$

Assumptions: Of the 3 vibration inputs possible, 2 are X and Z. Assume X is Channel 1, Z is Channel 2 for the above table.

Figure 12 BIODYN-80 Transfer Functions Which May Be Used as PIVIB Input

1. Specify title for run

2. BDMOD - enter the biodynamic response module

   a. FREQS - specify all frequencies required for biodynamic analysis

   b. VIBR - specify vibration input/source transfer functions

   c. BIOTR - specify biodynamic transfer functions. This is the interface between BIODYN-80 and PIVIB.

   d. BDOUT - specify biodynamic outputs for printing

   e. BCOMP - given all information specified above, compute and print biodynamic quantities

3. PVMOD - enter the pilot/vehicle module

   a. Specify various P/V parameters in state vector form

   b. VBINT - controls communication between BDMOD and PVMOD

   c. PCOMP - perform pilot/vehicle computations and print results

   d. FDREP - compute and print frequency domain measures, e.g., describing functions, remnants, signal spectra

4. Repeat 2 and 3 for each case

5. END

E. FOR ASSISTANCE

New and inexperienced users should have an experienced INTERCOM or batch user assist them throught the first application. For technical questions concerning this program or models, please call or write: Henry R. Jex at Systems Technology, Inc., 13766 S. Hawthorne Blvd., Hawthorne, CA 90250. Telephone Number (213) 679-2281.

APPENDIX A

DEFINITION OF PARAMETERS, SYMBOLS, RANGES AND TYPICAL VALUES

TABLE 1 PARAMETER AND SYMBOL DEFINITIONS, RANGES, AND TYPICAL VALUES

PARA-METER	FORTRAN NAME	UNITS	LOCATION DEFINITION	SOURCE* (Refs.)	REASONABLE RANGE		TYPICAL VALUES (STD CASES)	
					MINIMUM	MAXIMUM	STDPLT†	STDTCRW
			LOWER BODY					
M_B	XMB	kg	Lower body mass (Hips)	T(1,2,3)	10.	25.	14.	14.
B_B	BB	n/m/s	Lower body/seat cushion damper	F(1,4,5)	100.	2,000.	1290.1	315.
K_B	XKB	N/m	Lower body/seat cushion stiffness	F(1,4,5)	20,000.	100,000.	29585.	49360.
K_{BS}	GK1	N/m	Series spring gradient in lower body	F(1,4,5)	50,000.	200,000.	71519.	119322.
θ_L	THL	deg	Seat (hips) tilt angle	M(1)	-20.	+80.	13.	13.
G	G	m/s2	Trim vertical acceleration		0.1	100.	9.8	9.8
			TORSO					
M_T	XMT	kg	Torso mass	T(1,2,3)	10.	30.	18.	18.
I_T	ZIT	kg.m2	Torso inertia	T(1,2,3)	0.5	2.	0.8	0.8
B_{TB}	BTB	N.m/rad/s	Torso damping	F(1,4)	10.	100.	16.75	40.
K_{TB}	XKTB	N.m/rad	Torso stiffness	G,F(1,4)	100.	2,000.	500.	500.
θ_T	THT	deg	Angle of XLT from vertical	M(1,3,4)	-30.	+90.	10.	-15.
L_T	XLT	m	Torso c.g. to hips pivot length	T,M(1,2,3)	0.12	0.40	0.15	0.15
θ_{TN}	THTN	deg	Angle of XLTN	M,T(1,2,3)	-30.	+90.	5.	-5.
L_{TN}	XLTN	m	Torso c.g. to neck/pivot	T,M(1,2,3)	0.15	0.30	0.3	0.3
θ_S	THS	deg	Angle of XLS	M,T(1,3)	-30.	+90.	5.	-5.
L_S	XLS	m	Torso c.g. to shoulder length		0.10	0.30	0.3	0.3

†"STDPLT" = STD pilot, stiff centerstick
†"SDTCRW" = STD crewman, hand on knees

*Sources Legend: Measured (e.g., photo) or specified by situation
Tabulated, cadaver or anthropometric tables
Fitted, to transfer function data
Guesstimate (on basis of physical properties)

(continued)

TABLE 1. (Continued)

PARAMETER	FORTRAN NAME	UNITS	LOCATION DEFINITION	SOURCE* (Refs.)	REASONABLE RANGE MINIMUM	REASONABLE RANGE MAXIMUM	TYPICAL VALUES (STD CASES) STDPLT	TYPICAL VALUES (STD CASES) STDCRW
			NECK					
M_N	XMN	kg	Neck mass	T(1,3,6)	0.	3.0	0.0**	1.24
I_N	ZIN	kg.m^2	Neck inertia	T(1,2,3,6)	0.	0.010	0.0**	0.0024
B_N	BNT	N.m / rad/s	Neck/torso damper	G,F(1,5)	0.	0.40	0.25	0.1
K_{NT}	XKNT	N.m / rad	Neck/torso stiffness	G(1,5)	10.	80.	50.0	50.0
θ_N	THN	deg	Angle of XLN	M(1,3)	-90.	+90.	-20.	-30.
L_N	XLN	m	Neck length	M,T(1,2,3,6)	0.05	0.25	0.1	.12444
L_{N1}	XLN1	m	Neck c.g to neck/torso pivot	T,G(1,3)	0.02	0.15	0.05	.06222
			HEAD/DISPLAY VIEWING					
M_H	XMH	kg	Head mass	T,G(1,2,3,5)	2.0	10.0 helmeted	4.34	3.1
I_H	ZIH	kg.m^2	Head inertia	T,G(1,2,3,6)	0.010	0.100 helmeted	0.039	0.0303
B_{HN}	BHN	N.m / rad/s	Head/neck damper	G,F(1,8)	0.	0.40	0.0**	0.126
K_{HN}	XKHN	N.m / rad	Head/neck stiffness	G,F(1,4,8)	10.	30.	10.**	15.
C_H	CH	-	Head/neck compliance parameter (CH = 0. locks head on neck)	M(1,8)	0.0 locked	1. unlocked	0.0**	1.
θ_H	TH	deg	Angle of XLG(pivot-CG)	M,T(1,2,3,6)	-30.	+150.	70.	60.
L_T	XLH	m	Head c.g. to head/neck pivot length	T,M(1,2,3,6)	0.0	0.100	0.0*	0.025
θ_V	THV	deg	Angle of line of sight	M,T(1,3)	-90.	+90.	-30.	-30.
V_D	VD	m	Viewing distance from head/neck pivot	M(1)	0.	1000.	0.75	0.6853

*Sources Legend:
Measured (e.g., photo) or specified by situation
Tabulated, cadaver or anthropometric tables
Fitted, to transfer function data
Guesstimate (on basis of physical properties)

**Head/Neck Locked

TABLE 1. (Continued)

PARAMETER	FORTRAN NAME	UNITS	LOCATION DEFINITION	SOURCE* (Refs.)	REASONABLE RANGE MINIMUM	REASONABLE RANGE MAXIMUM	TYPICAL VALUES (STD CASES) STDPLT	TYPICAL VALUES (STD CASES) STDCRW
			ARMS (Upper, Lower)					
M_1	XM1	kg	Upper arm mass	T,M(1,2,3)	1.0	4.0	1.372	1.372
I_1	Z1	$kg.m^2$	Upper arm inertia	T(1,2,3)	0.01	0.05	0.012	0.012
θ_1	TI	deg	Upper arm angle	M,T(1,3,8)	-30.0	+90.0	40.	15.
L_1	D1	m	Upper arm length (= $L_a + L_b$)	M,T(1,3,8)	0.2	0.5	0.29	0.29
L_a/L_1	R1	m/m	Upper arm c.g. (factional distance	T,G(1,2,3)	0.2	0.6	0.44	0.44
M_2	XM2	kg	Lower arm mass	T,M(1,2,3)	0.5	3.0	1.017	1.017
I_2	Z2	$kg.m^2$	Lower arm inertia	T,(1,2,3)	0.01	0.10	0.0152	0.0152
θ_E	TE	deg	Elbow angle	M,T(1,3,8)	60.0	170.0	145.	115.
L_2	D2	m	Lower arm length (= $L_e + L_d$)	M,T(1,3,8)	0.2	0.5	0.305	0.305
L_d/L_2	R2	m/m	Lower arm c.g. (fractional distance)	T,G(1,2,3)	0.2	0.6	0.5	0.5
			GRIP INTERFACE					
θ_{IJ}	TIJ	deg	Grip interface angle	M,G(3)	-45.0	+45.0	0.0	0.0
B_I/K_I	TIF	s	Grip interface time constant	G,F(1,8)	0.0	0.5	0.01	0.1
C_I	CI	m/N	Grip interface compliance K_I-1	M,G,F(1,8)	0.0 fixed	1000.0 "free"	.0000558	1.0

*Sources Legend: Measured (e.g., photo) or specified by situation
Tabulated, cadaver or anthropometric tables
Fitted, to transfer function data
Guesstimate (on basis of physical properties)

TABLE 1. (Continued)

PARAMETER	FORTRAN NAME	UNITS	LOCATION DEFINITION	SOURCE* (Refs.)	REASONABLE RANGE		TYPICAL VALUES (STD CASES)	
					MINIMUM	MAXIMUM	STDPLT	STDCRW
			STICK					
M_S	XMS	kg	Stick/hand mass (referred to grip)	M,F(1,8)	0.0	1.0	1.31	4.0
B_S	BS	N/m/s	Stick damper	M,F(1,8)	0.0	5.0	2.	240.0
K_S	XKS	N/m	Stick gradient	M(1,8)	0.01	20,000.0	13900.	10000.0
C_{KS}	CKS	-	Stick compliance parameter (CKS=0 means that XKS→∞	M(1)	0.0 "fixed"	1.0 "fixed"	1.0	1.0
S_X	SX	N/g	Bobweight sensitivity to N_X	F,M,G(1,8)	-5.0	+10.0	0.0	0.0
S_Z	SZ	N/g	Bobweight sensitivity to N_Z	F,M,G(1,8)	-10.0	+10.0	0.0	0.0
θ_C	THC	deg	Stick angle	M(1)	-20.0	+120.0	90.	90.
L_C	XLC	m	Stick length (pivot to center of grip)	M(1)	0.0	2.0	0.61	0.55
K_{SC}	XKSC	Units/m	Stick output scale factor (rescales stick displacement to "specified" units (e.g., deg, cm, etc.)	F,G(1,8)	0.01	20,000.0	13900.(N/m)	0.01
			ARM REST					
B_{AR}	BAR	N/m/s	Arm rest damper (normal)	M,G(1)	0.0	1.0	0.0†	0.0†
K_{AR}	XKAR	N/m	Arm rest stiffness (normal)	M,G(1)	0.0	10,000.0	0.0†	0.0†
B_F	BAT	N/m/s	Arm rest damper (tangential)	G,M(1)	0.0	150.0	0.0†	0.0†
K_F	XKAT	N/m	Arm rest stiffness (tangential)	G,M(1)	0.0	10,000.0	0.0†	0.0†
L_{ER}	XLER	m	Elbow to arm rest distance	M(1)	0.0	0.5	0.0†	0.0†
A_{rmR}	ARMR	-	Fraction of arm weight on arm rest	G(1)	0.0	1.0	0.0†	0.0†

*Sources Legend: Measured (e.g., photo) or specified by situation
Tabulated, cadaver or anthropometric tables
Fitted, to transfer function data
Guesstimate (on basis of physical properties)

†Armrest disabled.

TABLE 1. (Continued)

PARAMETER	FORTRAN NAME	UNITS	LOCATION DEFINITION	SOURCE* (Refs.)	REASONABLE RANGE MINIMUM	REASONABLE RANGE MAXIMUM	TYPICAL VALUES (STD CASES) STDPLT	TYPICAL VALUES (STD CASES) STDCRW
			NEUROMUSCULAR SYSTEM: Actuation Elements:					
NM	NM	-	Switch for central or force activation dynamics 0 for arm control 1 for head/neck control	M	0.0 arm	1.0 head	0.0	0.0
S_i	SI	-	Overall scale factor	F,G(1,8)	0.0	200.0	104.4	50.0
K_{1c}	XK1C	N/N	Neuromuscular actuation game	F,G(1,8)	0.0	1.0	.02044	.02
T_{cc}	TCC	s	Neuromuscular actuation game	F,G(1,8)	0.0	0.2	.0909	.0909
cs	TCS	s	Neuromuscular actuation lag	F,G(1,8)	0.0	0.3	0.089	.089
K_a	XKAA	N/N	Gain of force activation dynamics	F,G(1,8)	0.0	10.0	1.	1.
ζ_a	ZA	-	Damping in force activation dynamics	F,G(1,8)	0.0	1.0	0.8	0.8
ω_a	WA	rad/s	Natural frequency in force activation dynamics	F,G(1,8)	10.0	20.0	16.	16.
τ_a	TAA	s	Time delay in force activation dynamics	F,G(1,8)	0.0	0.10	0.0	0.0

*Sources Legend: Measured (e.g., photo) or specified by situation
Tabulated, cadaver or anthropometric tables
Fitted, to transfer function data
Guesstimate (on basis of physical properties)

TABLE 1. (Continued)

PARAMETER	FORTRAN NAME	UNITS	LOCATION DEFINITION	SOURCE* (Refs.)	REASONABLE RANGE MINIMUM	REASONABLE RANGE MAXIMUM	TYPICAL VALUES (STD CASES) STDPLT	TYPICAL VALUES (STD CASES) STDCRW
			NEUROMUSCULAR SYSTEM: <u>Actuation Elements: continued</u>					
B_M	BM	N/m/s	"Hills law" damper	G,F(1,7,8)	0.0	20.0	1.	1.0
K_M	XKM	N.m	Spring in neuromuscular system	G,F(1,7,8)	0.1	20.0	2.	2.
B_e	BE	N/m/s	Series elastic element damper	F(1,7,8)	0.0	10.0	2.431	2.43
K_e	XKE	N/m	Series elastic element gradient	G,F(1,7,8)	0.1	100.0	40.	40.
B_T	BT	N/m/s	Tendon damper	G,F(1,7,8)	0.0	10.0	0.	0.
K_T	XKT	N/m	Tendom gradient	G,F(1,7,8)	0.1	300.0	80.	80.
K_{sp}	XKSP	N/m	Muscle spindle model gain	G(1,7,8)	1.0	10.0	5.	5.
T_{sp}	TSP	s	Muscle spindle lead time constant	G(1,7,8)	0.02	0.15	1/11.	1/11.
T_{ps}	TPS	s	Muscle spindle lag time constant	G(1,7,8)	0.0	0.1	0.0	0.0
T_{ss}	TSS	s	Muscle spindle high frequency lead time constantly	G(1,7,8)	0.0	0.1	0.0	0.0
K_g	XKG	N/N	Golgi tendon organ model gain	G(1,7,8)	0.1	1.0	0.5	0.5
T_g	TG	s	Golgi tendon organ time constant	G(1,7,8)	0.02	0.1	1/18.	1/18.
T_z	TZ	s	Golgi tendon organ time constant	G(1,7,8)	0.0	0.1	0.0	0.0
T_p	TP	s	Golgi tendon organ lag time constant	G(1,7,8)	0.0	0.1	0.0	0.0

*<u>Sources Legend:</u> <u>M</u>easured (e.g., photo) or specified by situation
<u>T</u>abulated, cadaver or anthropometric tables
<u>F</u>itted, to transfer function data
<u>G</u>uesstimate (on basis of physical properties)

TABLE 1. (Concluded)

PARAMETER	FORTRAN NAME	UNITS	LOCATION Definition	SOURCE* (Refs.)	REASONABLE RANGE MINIMUM	MAXIMUM	TYPICAL VALUES (STANDARD CASES) STDPLT	STDCRW
			IMAGE FIXATION/VESTIBULO-OCULAR SERVO					
K_{OE}	XKOE	rad/rad	Fixation error gain	F (9)	1.0	10.0	7.08	7.08
K_{RE}	XKRE	rad/(rad/s)	Fixation rate gain	F (9)	0.0	10.0	0.0	0.0
τ_V	TV	s	Time delay in fixation loop	F (9)	0.0	0.10	0.045	0.045
α	ALPHA	rad/s	"Pseudo Integrator" break frequency	G, F(9)	0.0	0.5	0.3	0.3
K_p	XKP	rad/rad	Target pursuit gain (Optional)	G (9)	0.0	1.0	0.0	0.0
K_{IE}	XKIE		Position gain from "Vestibular" sensor	F (9)	0.1	1.0	0.67	0.67
K_{VE}	XKVE		Velocity gain from "Vestibular" sensor	F (9)	0.0	0.1	0.1	0.1
T_{c2}	TC2		"Vestibular" lag	F, T(9)	0.005	0.015	0.01	0.01
T_{EM}	TEM	s	Ocular Servo Lag time constant	F (9)	0.05	0.10	0.1	0.1
T_{LM}	TLM	s	Ocular Servo Lead time constant	F (9)	0.010	0.020	0.0125	0.0125
Q_E	QE		Switch for fast mode in Ocular Servo 1. use ZE,WE 0. WE = infinity	M	0.0 ($\omega_E=\infty$)	1.0	1.0	1.0
ζ_e	ZE	-	Ocular Servo Damping Ratio	F (9)	0.2	1.0	0.65	0.65
ω_e	WE	rad/s	Ocular Servo Natural frequency	F (9)	200.0	400.0	316.23	316.23

*Sources Legend: Measured (e.g., photo) or specified by situation
Tabulated, cadaver or anthropometric tables
Fitted, to transfer function data
Guesstimate (on basis of physical properties)

TABLE 2. PARAMETER FILE STRUCTURE (SHORT FORMAT)

A.	Lower Body					
	M_B	B_B	K_B	K_{BS}	θ_L	G
B.	Torso					
	M_T	I_T	B_{TB}	K_{TB}		
	θ_T	L_T	θ_{TN}	L_{TN}	θ_s	L_s
C.	Neck					
	M_N	I_N	B_{NT}	K_{NT}		
	θ_N	L_N	L_{N1}			
D.	Head/Display Viewing					
	M_H	I_H	B_{HN}	K_{HN}	C_H	
	θ_H	L_H	θ_V	V_D		
E.	Arms (Upper then lower)					
	M_1	I_1	θ_1	L_1	L_a/L_1	
	M_2	I_2	θ_E	L_2	L_d/L_2	
F.	Grip Interface					
	θ_{LJ}	B_I/K_I	C_I			
G.	Stick					
	M_s	B_s	K_s	C_{KS}	S_x	S_z
	θ_c	L_c	K_{sc}			

H. Arm Rest

B_{AR} K_{AR} B_F K_F L_{ER} Arm_R

I. Neuromuscular System

NM S_i

K_{1c} T_{cc} τ_{cs}

K_a ζ_a ω_a τ_a

B_M K_M B_e K_e B_T K_T

K_{sp} T_{sp} T_{ps} T_{ss}

K_g T_g T_z T_p

J. Image Fixation/Vestibulo-Ocular Servo

K_{DE} K_{RE} τ_v α K_p

K_{IE} K_{VE} T_{c_2}

T_{EM} T_{LM} Q_E ζ_e ω_e

APPENDIX B
DEFINITION OF FORCING FUNCTION AND RESPONSE VARIABLES

TABLE 3 INPUT (FORCING FUNCTION) VARIABLES

MATRIX COLUMN NUMBER	INPUT VARIABLE NAME	COLUMN CODE*	UNITS	POSITIVE DIRECTION	DEFINITION AND USAGE
1	N_{zp}	NZP	g	Upward	Platform acceleration
2	Δ_{zp}	DZP	m	Upward	Platform deflection
3	N_{xp}	NXP	g	Forward	Platform acceleration
4	Δ_{xp}	DXP	m	Forward	Platform deflection
5	F_D	bFD	N	Forward	Force input to stick
6	B_{zp}	BZP	m	Upward	Special Platform deflection+
7	B_{xp}	BXP	m	Forward	Special Platform deflection+
8	NMC	NMC	N		Neuromuscular command within CNS
9	θ_{TI}	TTI	rad		Test input into fixation error

*Small "b" represents a typed-blank space.

+These are used to get transfer functions of $\frac{\text{Inertial shoulder (or head) motion}}{\text{Platform motion}}$

TABLE 4 OUTPUT (RESPONSE) VARIABLES

MATRIX COLUMN NUMBER	RESPONSE VARIABLE NAME	MATRIX COLUMN CODE*	UNITS	POSITION DIRECTION	DEFINITION AND USAGE
1	c	bCb	m or N	Forward	Stick output (K_{cs} used to scale as force)
2	f_{ca}	FCA	N	Forward on stick	Interface force at stick grip
3	Δz_1	bZ1	m	Upward	Vertical shoulder deflection relative to platform (z_s-z_p)
4	$\Delta\theta_1$ †	DT1	rad	Pitch up	Lower arm angle
5	$\Delta\theta_a$	DTA	rad	Pitch up	Lower arm angle
6	f_{1y}	F1Y	rad	Up on upper arm	Vertical interface force at elbow
7	F_M	bFM	N		Muscle model force referred to upper arm c.g.
8	L_I	bLI	N	Forward	Grip interface deflection (stick to lower arm)
9	f_{1x}	F1X	N	Forward on upper arm	Horizontal interface force at elbow
10	x_m	bXM	m		Internal state in muscle model
11	f_{ns}	FNS	N	Forward on upper arm	Horizontal interface force at shoulder/upper arm
12	f_{vs}	FVS	N	Up on upper arm	Vertical interface force at shoulder/upper arm
13	x_s	bXS	m	Forward	Horizontal shoulder deflection relative to platform (x_s-x_p)
14	$\Delta\theta_T$	DTT	rad	Pitch up	Torso rotation
15	f_{nh}	FNH	N	Forward on	Head/neck interface force
16	$\Delta\theta_H$	DTH	rad	Pitch up	Head rotation
17	f_{vh}	FVH	N	Up on head	Head/neck interface force
18	f_{by}	FBY	N	Up on Torso	Vertical hips/torso interface force
19	F_{bx}	FBX	N	Forward on hips	Hips/torso interface force

*Note: Small "b" represents a typed-blank space.
†Note: $\Delta\theta_1$ (Column 4) means small signal perturbation of θ_1 given in fig. 3

TABLE 4 (Continued)

MATRIX COLUMN NUMBER	RESPONSE VARIABLE NAME	MATRIX COLUMN CODE*	UNITS	POSITIVE DIRECTION	DEFINITION AND USAGE
20	u_{5p}	U5P	m	Up the seat back	Internal state in hip model
21	u_{bp}	UBP	m	Up the seat back	Hip deflection relative to platform (parallel to seat-back)
22	x_1	b̸X1	m		Internal state in muscle model
23	$\Delta\theta_N$	DTN	rad	Pitch up	Neck rotation
24	f_{nN}	FNN	N	Forward on neck	Neck/torso horizontal interface force
25	f_{vN}	FVN	N	Up on neck	Neck/torso vertical interface force
26	RHD	RHD	deg	Up relative to display	Head point of Regard relative to a display on the platform
27	A_a	b̸AA	N		Muscle model command out of spinal cord
28	F_A	b̸FA	N		Commanded force out of force activation dynamics
29	f_{aa}	FAA	N		Internal state in force activation
30	A_g	b̸AG	N		Output of golgi tendon organ sensors
31	A_c	b̸AC	N		Spinal cord command
32	A_E	b̸AE	N		Error between neuromuscular command and proprioceptive stick force
33	x_{sp}	XSP	m		Muscle length change sensed by spindle model
34	Δr_n	DRN	m		Relative normal deflection of arm and rest
35	Δr_t	DRT	m		Relative tangential deflection of arm and rest
36	Δz_h	DZH	m		Vertical component of head motion relative to platform

*Note: Small "b̸" represents a typed-blank space.

TABLE 4 (Concluded)

MATRIX COLUMN NUMBER	RESPONSE VARIABLE NAME	MATRIX COLUMN CODE*	UNITS	POSITIVE DIRECTION	DEFINITION AND USAGE
37	A_{C1}	AC1	rad		Output of compensatory action in eye fixation loop
38	A_{E1}	AEI	rad		Output of "Pseudo Integrator"
39	θ_{MC}	TMC	rad		Command to Ocular Servo
40	A_V	bAV	r/s	Head up	Output of "Vestibular" Sensor
41	θ_{EH}	TEH	rad	Up	Eye rotation relative to head
42	θ_{M1}	TM1	rad		Internal node in Ocular Servo
43	θ_I	THI	rad	Up	Fixation error
44	RED	RED	m	Eye up rel. to display	Relative eyem point of regard at display
45	θ_{TC}	TTC	rad		Output of "Image Pursuit" operation
46	Z_T	ƀZT	m	Up	Display inertial displacement (vertical)
47	θ_E	THE	rad	Up	Inertial eye rotation
48	Δx_h	DXH	m	Forward	Horizontal component of head motion relative to platform

*Note: Small "ƀ" represents a typed-blank space.

APPENDIX C

EQUATIONS OF MOTION

1

$$\underbrace{(\sin\theta_c)c}_{\text{if } C_{K_s} \neq 0} - x_s - L_1(\cos\theta_1)\Delta\theta_1 + L_2(\sin\theta_a)\Delta\theta_a - L_T(\cos\theta_{IJ}) = -B_{X_p}$$

2

$$\underbrace{\left\{-(M_s s^2 + B_s s + K_s) - \frac{S_x}{L_c} - M_2(\cos\theta_c)^2 s^2\right\} c/K_{sc}}_{\text{if } C_{K_s} \neq 0} - \underbrace{c}_{\text{if } C_{K_s} = 0}$$

$$+ (\sin\theta_c)Lca + (\cos\theta_c)L_{1y} - M_2(\cos\theta_c)(\sin\theta_{IJ})s^2 L_I$$

$$- M_2 L_d(\cos\theta_c)(\cos\theta_a)s^2\Delta\theta_a + (\cos\theta_c)(B_{AR}s + K_{AR})(\Delta r_n)$$

$$+ (\cos\theta_c)(B_F s + K_F)(\Delta r_t)$$

$$= -(\ _z/g + M_2 \cos\theta_c)a_{z_p} - S_x/g\ a_{xp} - F_d$$

3

$$\Delta z_1 + L_1(\sin\theta_1)\Delta\theta_1 + L_2(\cos\theta_a)\Delta\theta_a + L_T(\sin\theta_{IJ}) + \underbrace{\frac{(\cos\theta_c)}{K_{sc}}}_{\text{if } C_{K_s} \neq 0} c = 0$$

4

$$\left\{ I_1 s^2 + (L_d M_1 g + L_1 M_2 g - L_1 F_{av_O})\cos\theta_1 \right\}\Delta\theta_1 - L_b(\sin\theta_1)f_{1_y}$$

$$+ L_b(\cos\theta_1)f_{1_x} + L_a(\cos\theta_1)f_{ns} + La(\sin\theta_1)f_{vs} - S_1 L_a F_M = 0$$

NOTE: $F_{av_O} = Arm_R\ (M_1 + M_2)g$; $\theta_a = 90 + \theta_1 - \theta_E$;

$$a_{z_p} = gNz_p + s^2(\Delta z_p + Bz_p) \ ; \ a_{x_p} = gN_{x_p}t + s^2(\Delta x_p + B_{x_p})$$

5 $$\left\{(I_2 + M_2L_d^2\cos^2\theta_a)s^2 + (F_{av_0} - M_2g)L_e\sin\theta_a\right\}\Delta\theta_a - L_e(\sin\theta_a)f_{1_x}$$

$$- L_2(\cos\theta_a)f_{1_y} - L_d(\sin\theta_a)f_{c_a}$$

$$- (L_e - L_{ER} + L_d\cos^2\theta_a)(B_{A_R}s + K_{A_R})\Delta r_n$$

$$- (L_d\sin\theta_a\cos\theta_a)(B_Fs + K_F)\Delta r_T$$

$$+ \overbrace{\frac{L_dM_2(\cos\theta_a)(\cos\theta_c)s^2}{K_{sc}}}^{\text{if } C_{K_s} \neq 0}c + L_d(\cos\theta_a)M_2(\sin\theta_{IJ})s^2L_I = L_d(\cos\theta_a)M_2a_{z_p}$$

6 $$f_{1_y} + f_{vs} - M_1s^2\Delta z_1 - M_1L_a(\sin\theta_1)s^2\Delta\theta_1 = M_1a_{z_p}$$

8 $$C_I(\cos\theta_{IJ})f_{c_a} + \left\{C_I(\sin\theta_{IJ})^2M_2s^2 + B_I/K_I + 1\right\}L_I$$

$$+ C_I(\sin\theta_{IJ})(\cos\theta_a)M_2L_ds^2\Delta\theta_a$$

$$\overbrace{+ \frac{C_I(\sin\theta_{IJ})(\cos\theta_c)M_2s^2c}{K_{sc}}}^{\text{if } C_{K_s} \neq 0} - C_I(\sin\theta_{IJ})f_{1_y}$$

$$+ C_I(\sin\theta_{IJ})\ [-(B_Fs + K_F)(\sin\theta_a)\Delta r_t]$$

$$= C_I(\sin\theta_{IJ})M_2a_{z_p}$$

$$+ C_I(\sin\theta_{IJ})\ [-(B_{AR}s + K_{AR})(\cos\theta_a)\Delta r_n]$$

9 $$\overbrace{-\frac{M_2(\sin\theta_c)s^2}{K_{sc}}}^{\text{if } C_{K_s} \neq 0}c + M_2(\cos\theta_{IJ})s^2L_I - \left\{(M_2L_d\sin\theta_a)s^2 + F_{av_0}\right\}\Delta\theta_a$$

$$+ f_{1_x} - f_{c_a} - (B_Fs + K_F)(\cos\theta_a)\Delta r_t + (B_{AR}s + K_{AR})(\sin\theta_a)\Delta r_n = M_2a_{x_p}$$

11 $$f_{ns} - f_{1_x} - M_1 s^2 x_s - M_1 L_a(\cos\theta_1) s^2 \Delta\theta_1 = M_1 a_{x_p}$$

12 $$f_{vs} + f_{VN} - f_{by} + M_T(\cos\theta_L) s^2 u_{bp} - M_T L_T(\sin\theta_T) s^2 \Delta\theta_T = -M_T a_{z_p}$$

13 $$x_s + (\sin\theta_L) u_{bp} + (L_T\cos\theta_T + L_s\cos\theta_s)\Delta\theta_T = B_{x_p}$$

14
$$[I_T s^2 + (B_{TB} + B_{NT})s + K_{TB} + K_{NT} - W_E]\,\Delta\theta_T - (B_{NT}s + K_{NT})\Delta\theta_N$$

$$- (L_s\cos\theta_s) f_{ns} - L_{TN}(\cos\theta_{TN}) f_{nN} - L_s(\sin\theta_s) f_{vs}$$

$$- L_{TN}(\sin\theta_{TN}) f_{VN} + L_T(\cos\theta_T) f_{bx}$$

$$- L_T(\sin\theta_T) f_{by} + S_i L_a F_M = 0$$

$$W_E = L_T\cos\theta_T[(M_H + M_N + M_T + M_1 + M_2)g - F_{av_0}]$$

$$+ L_s\cos\theta_s[(M_1 + M_2)g - F_{av_0}] + L_{TN}\cos\theta_{TN}(M_H + M_N)g$$

15
$$f_{nh} + M_H(\sin\theta_L) s^2 u_{bp} + M_H(L_T\cos\theta_T + L_{TN}\cos\theta_{TN}) s^2 \Delta\theta_T$$

$$+ M_H L_N(\cos\theta_N) s^2 \Delta\theta_N + M_H L_H(\cos\theta_H) s^2 \Delta\theta_H = M_H a_{x_p}$$

16
$$[(I_H s^2 + B_{HN}s - M_H g L_H\cos\theta_H) C_H + K_{HN}]\Delta\theta_H \overbrace{+ F_A}^{\text{if } NM \neq 0}$$

$$-(B_{HN}C_H s + K_{HN})\Delta\theta_N - C_H L_H(\sin\theta_H) f_{vh} - C_H L_H(\cos\theta_H) f_{nh} = 0$$

17
$$f_{vh} - M_H(\cos\theta_L) s^2 u_{b_p} + M_H(L_T\sin\theta_T + L_{TN}\sin\theta_{TN}) s^2 \Delta\theta_T$$

$$+ M_H L_N(\sin\theta_N) s^2 \Delta\theta_N + M_H L_H(\sin\theta_H) s^2 \Delta\theta_H = M_H a_{z_p}$$

18 $$(\cos\theta_L)f_{by} + (B_B s + K_B)u_{5p} + (\sin\theta_L)f_{bx} + M_B s^2 u_{bp} = M_B(\sin\theta_L)a_{x_p} - M_B(\cos\theta_L)a_{z_p}$$

19 $$f_{bx} + f_{nN} + f_{ns} - M_T L_T(\cos\theta_T)s^2\Delta\theta_T - M_T(\sin\theta_L)s^2 u_{b_p} = -M_T a_{x_p}$$

20 $$\left(\frac{B_B s + K_B}{K_{BS}} + 1\right) u_{5p} - u_{bp} = 0$$

21 $$(\cos\theta_L)u_{bp} - (L_T\sin\theta_T + L_s\sin\theta_s)\Delta\theta_T - \Delta z_1 = o - B_{z_p}$$

23 $$[I_N s^2 + B_{NT}s + K_{NT} - (M_H g L_N + M_N g L_{N_1})\cos\theta_N]\Delta\theta_N$$
$$- L_{N_1}(\sin\theta_N)f_{VN} - L_{N1}(\cos\theta_N)f_{nN} - [(L_N - L_{N1})\sin\theta_N + L_H\sin\theta_H]\, f_{vh}$$
$$- [L_H\cos\theta_H + (L_N - L_{N1})\cos\theta_N]f_{nh} + [I_H s^2 - M_H g L_H\cos\theta_H]\Delta\theta_H$$
$$- (B_{NT}s + K_{NT})\Delta\theta_T = 0$$

24 $$f_{nN} - f_{nh} + M_N(\sin\theta_L)s^2 u_{bp} + M_N(L_T\cos\theta_T + L_{TN}\cos\theta_{TN})s^2\Delta\theta_T + M_N(L_{N_1}\cos\theta_N)s^2\Delta\theta_N = M_N a_{x_p}$$

25 $$f_{VN} - f_{vh} - M_N(\cos\theta_L)s^2 u_b + M_N(L_T\sin\theta_T + L_{TN}\sin\theta_{TN})s^2\Delta\theta_T + M_N(L_{N_1}\sin\theta_N)s^2\Delta\theta_N = M_N a_{z_p}$$

NEUROMUSCULAR MODEL EQUATIONS

7
$$F_M + (B_T s + K_T) La(\Delta\theta_1) - (B_T s + K_T) x_m = 0$$

10
$$F_M + (B_e s + K_e) x_m - (B_e s + K_e) x_1 = 0$$

22
$$F_M - (B_M s + K_M) L_a(\Delta\theta_T) + (B_M s + K_M) x_1 + \underbrace{F_A}_{\text{if NM} = 0} = 0$$

27
$$(T_{ps} s + 1)(A_a + A_g - A_c) - \overbrace{K_{sp}(T_{sp} s + 1)(T_{ss} s + 1) x_{sp}}^{\text{if NM} = 0} = 0$$

28
$$(\tau_a s + 2) F_A + K_a(\tau_a s - 2) F_{aa} = 0$$

29
$$\underbrace{\left[1 + \frac{2\zeta_a}{\omega_a} s + \frac{s^2}{\omega_a^2}\right]}_{\substack{\text{This set to 1.0} \\ \text{if } \omega_a = 0}} F_{aa} - F_{aa} = 0$$

30
$$(T_p s + 1) A_g + \overbrace{K_g(T_g s + 1)(T_z s + 1) F_M}^{\text{if NM} = 0} = 0$$

31
$$(\tau_{cs} s + 2)(T_{cc} s + 1) A_c + K_{1c}(\tau_{cs} s - 2) A_E = 0$$

32

NM = 0

$$\left(\frac{M_2}{K_{sc}} \cos^2\theta_c s^2\right) c - \sin\theta_c f_{ca} + (M_2 L_d \cos\theta_a \cos\theta_c s^2)\Delta\theta_a - \cos\theta_c f_{1y}$$

$$+ (M_2 \sin\theta_{IJ} \cos\theta_c s^2) L_T - (B_{AR}\cos\theta_a\cos\theta_c s + K_{AR}\cos\theta_a\cos\theta_c)\Delta r_n$$

$$- (B_F \sin\theta_a \cos\theta_c s + K_F \sin\theta_a \cos\theta_c)\Delta r_t + A_E$$

$$= M_2 \cos\theta_c a_{z_p} + NMC$$

NM = 1

$$A_E + RHD/VD = NMC$$

33 $$x_{sp} + L_a \Delta\theta_T - x_m = 0$$

26 $$[L_T \sin(\theta_T - \theta_V) + L_{TN}\sin(\theta_{TN} - \theta_V)]\Delta\theta_T - V_D \Delta\theta H - \cos(\theta_L - \theta_V) u_{bp}$$

$$+ L_N \sin(\theta_N - \theta_V)\Delta\theta_N + RHD = B_{z_p}\cos\theta_V - B_{x_p}\sin\theta_V$$

34 $$\Delta r_n + \frac{\overbrace{c\ \cos(\theta_c - \theta_a)}^{\text{if } C_{Ks} \neq 0}}{K_{sc}} + (L_2 - L_{ER})\Delta\theta_a + L_I \sin(\theta_a - \theta_{IJ}) = 0$$

35 $$\Delta r_t - c\,\frac{\overbrace{\sin(\theta_c - \theta_a)}^{\text{if } C_{Ks} \neq 0}}{K_{sc}} + L_I \cos(\theta_a - \theta_{IJ}) = 0$$

36 $$\Delta z_H + (L_T \sin\theta_T + L_{TN} \sin\theta_{TN})\Delta\theta_T$$

$$- (\cos\theta_L)u_{bp} + (L_N \sin\theta_N)\Delta\theta N = B_{Z_P}$$

37 $$(2 + \tau_v s)A_{c1} + (\tau_v s - 2)(K_{RE}s + K_{DE})\theta_I = 0$$

38 $$(s + \alpha)A_{EI} + A_{c_1} + K_{IE}A_V = 0$$

39 $$\theta_{MC} - \theta_{TC} - A_{EI} + K_{VE}A_V = 0$$

40 $$(T_{c_2}s + 1)A_V - s\Delta\theta_H = 0$$

41 $$Q_E = 0 \; \{ \; \theta_{EH} - \theta_{M_1} = 0$$

$$Q_E = 1 \; \left\{ \; (1 + \frac{2\zeta_e}{\omega_e} s + \frac{s^2}{\omega_e^2})\theta_{EH} - \theta_{M_1} = 0 \right.$$

42 $$(1 + T_{EM}s)\theta_{M_1} - (1 + T_{LM}s)\theta_{M_C} = 0$$

43 $$\theta_I - \frac{RED}{V_D} = \theta_{TI}$$

44 $$[L_T \sin(\theta_T - \theta_V) + L_{TN}\sin(\theta_{TN} - \theta_V)]\Delta\theta_T - V_D\Delta\theta_H$$

$$-u_{bp}\cos(\theta_L - \theta_V) + \Delta\theta_N L_N \sin(\theta_N - \theta_V) - V_D\theta_{EH} + RED$$

$$= B_{z_p}\cos\theta_V - B_{x_p}\sin\theta_V$$

45 $$\theta_{TC} - \frac{K_p}{V_D} Z_D = 0$$

46 $$Z_D = \Delta z_p$$

47 $$\theta_E - \Delta\theta_H - \theta_{EH} = 0$$

48 $$\Delta x_h + (\sin\theta_L)u_{bp} + (L_T\cos\theta_T + L_{TN}\cos\theta_{TN})\Delta\theta_T + L_N(\cos\theta_N)\Delta\theta_N = B_{x_p}$$

APPENDIX D

TYMSHARE EXAMPLE PROBLEM

This appendix documents the use of CREATE, BIODYN and PLOT on the Tymshare System 31 PDP 10.* The computer dialog appears on the next several pages for a typical session. An existing PARAMETER file is modified, a CHOICES file is created, BIODYN generates the requested transfer functions (only one of which is illustrated), and PLOT produces a quick-look Bode plot. Throughout the dialog, all user inputs/ responses are underlined. The following 6 character filenames are accessed in the course of this example (these are not the Standard Pilot and Standard Crewman which are available on Tymshare):

	File Name	Title
Existing PARAMETER file:	BB19	"Stiff Stick"
Modified PARAMETER file:	SEMI	"Semi-Supine"
CHOICES file:	CHOSAR	
TF file:	TAPE19	

There are several differences between the CDC version of the BIODYN-80 package and its Tymshare counterpart. These are listed below:

- All three programs run interactively on Tymshare; all files are specified by the user during execution.

- CHOICES filename can be an existing file, whose name is to be modified. (In CDC, the CHOICES filename must be a new name.)

*A user planning to use BIODYN-80 on Tymshare should be familiar with the Tymshare manual, XEXEC, especially Section 3. At present, BIODYN-80 is not a current Tymshare Library Program, and a potential user should contact the second author for the required procedures.

- **Because of the above differences, there are slight changes in the dialog for the Tymshare version (e.g., the NEW PARAMETER FILE? query is not used, since the PDP-10 *software* can determine internally whether *or* not a new filename has been input).**

D.1 Running CREATE

```
EXE CREATE

LOADING
EXECUTION _
```

Execute CREATE

```
    INPUT PARAMETER FILENAME :
PB19
```

Interactive input of PARAMETER file to be modified

```
    LISTING DESIRED?
YE

    (LO)NG OR (SH)ORT LISTING?
SH

PARAMETERS FOR:

STIFF  STICK

LOWER BODY
 11.000      1290.1      29585.      71519.      13.000      9.8000
TORSO
 18.000      0.80000     16.750      500.00
 10.000      0.15000     5.0000      0.30000     5.0000      0.30000
NECK
0.00000      0.00000     0.25000     50.000
-20.000      0.10000     0.50000E 01
HEAD/DISPLAY VIEWING
 4.3400      0.39000E-01 0.00000     1.0000      0.00000
 70.000      0.00000     -30.000     0.75000
ARM (UPPER, LOWER)
 1.3720      0.12000E-01 40.000      0.29000     0.11000
 1.0170      0.15200E-01 145.00      0.30500     0.50000
GRIP INTERFACE
0.00000      0.10000E-01 0.55781E-04
STICK
0.31000      2.0000      13900.      1.0000      0.00000     0.00000
 90.000      0.61000     13900.
ARM REST
0.00000      0.00000     0.00000     0.00000     0.00000     0.00000
NEUROMUSCULAR SYSTEM
  0   21.40
0.20437E-01 0.90909E-01 0.89888E-01
 1.0000      0.00000     16.000      0.00000
 1.0000      0.0000      2.4312      40.000      0.00000     80.000
 5.0000      0.10900E-01 0.00000     0.00000
0.50000      0.55556E-01 0.00000     0.00000
IMAGE FIXATION/VESTIBULO-OCULAR SERVO
 2.0295      0.00000     0.15000E-01 0.30000     0.00000
0.67000      0.10000     0.10000E 01
0.10000      0.12000E-01 1.0000      0.65000     316.23
```

Generate short listing of file to modify

```
    CHANGES DESIRED ?
YE

    INPUT MNEMONIC(5 CHARS) AND VALUE FOR EACH CHANGE,
    TO EXIT, TYPE XXX.
THE   .6.
TH    .110.
XXX
```

Make changes to file

(continued on next page)

D.1 (Continued)

```
    [illegible]
    [illegible] ?
[illegible]
    [illegible] TITLE :
[illegible]
     [illegible] DESIRED?
[illegible]
    [illegible] LISTING?
[illegible]
  [illegible] FOR:
[illegible]
 [illegible]
 [illegible]       1270.1      [illegible]      71519.      [illegible]   [illegible]
[illegible]
 [illegible]     0.80000     [illegible]     500.00
 [illegible]     [illegible]     [illegible]     0.30000     [illegible]   [illegible]
[illegible]
[illegible]     [illegible]     [illegible]     [illegible]
[illegible]     0.10000     [illegible]E-01
[illegible] VIEWING
 [illegible]     0.39000E-01 [illegible]     1.0000     [illegible]
 [illegible]     [illegible]     [illegible]     0.75000
[illegible] POWER
 [illegible]     [illegible]     [illegible]     0.29000     [illegible]
 [illegible]     [illegible]     [illegible]     0.30000     [illegible]
[illegible]
[illegible]     [illegible]     [illegible]
[illegible]
[illegible]     [illegible]     13900.     1.0000     0.00000     [illegible]
 [illegible]     [illegible]     [illegible]
[illegible]
[illegible]     [illegible]     [illegible]     0.00000     0.00000     [illegible]
 [illegible] SYSTEM
   [illegible]1.10
[illegible]     [illegible]     [illegible].89888E-01
 [illegible]     [illegible]     [illegible]     0.00000
 [illegible]     [illegible]     [illegible].4312     40.000     0.00000     [illegible]
 [illegible]     [illegible]     [illegible]     0.00000
 [illegible]     [illegible]     [illegible]     0.00000
[illegible] OCULAR SERVO
 [illegible]     [illegible]     [illegible]     0.30000     0.00000
 [illegible]     [illegible]     [illegible].10000E-01
 [illegible]     [illegible]     1.0000     [illegible]     [illegible]
    [illegible] FOR PARAMETER FILE :
[illegible]
```

Modify title for PARAMETER file

Short listing of modified file

Interactive input of filename on which to store modified PARAMETER file

(Continued on next page)

D.1 (Concluded)

```
    INPUT CHOICES FILENAME :
CHOSAR
```

Interactive input of CHOICES filename

```
    BIODYN TFS DESIRED FOR PIVIB ?
NO
```

No PIVIB TF's desired

```
    TRANSFER FUNCTION INPUT :
    FIRST LINE-RESPONSE MNEMONIC, FORCING FUNCTION MNEMONIC
       (AAA,AAA) ; ENTER XXX TO STOP
    SECOND LINE-PLOTTING INFORMATION, 5 ITEMS :
       BODE LOWER FREQ. LIMIT
       BODE UPPER FREQ. LIMIT
       BODE UPPER PHASE LIMIT (0. DEFAULTS TO 200.)
       BODE LOWER PHASE LIMIT (0. DEFAULTS TO -400.)
       LIST (1. TO LIST TABLE, 0. FOR NO LIST)
    IF NO PLOT DESIRED, ENTER 0. FOR ALL ITEMS
```

Format for CHOICES file information input

```
 C ,NZF
1.,100.,0.,0.,0.
 Z1,DZF
1.,100.,0.,0.,0.
DTH,DZF
1.,100.,0.,0.,1.
XXX
```

Input CHOICES file information

```
EXIT
```

Exit CREATE

D.2 Running BIODYN

```
-EXE BDNBO,NIRFN
LOADING
EXECUTION
```

Execute BIODYN

```
ENTER INPUT FILE NAME:    SEMI

ENTER CHOICES FILE NAME:  CHOSAR
```

Interactive input of PARAMETER and CHOICES files

```
                    11-Mar-80     11:53
```

BIODYN execution

```
CASE:    SEMI-SUPINE
```

Case title

```
ENTER SYSTEM OUTPUTS    FILE NAME?   TAPE20
NEW FILE
```

Interactive input of TF file

```
FLOATING UNDERFLOW       PC=111246

FLOATING UNDERFLOW       PC=111246

 DENOMINATOR:

   .10444E-26
  ( 16.591     )  ( 46.384     )  ( 56.079     )  ( 97.512
  ( 100.00     )  ( 285.86     )  ( 353.22     )
  (( .44231    , 8.3929    , 3.7123    , 7.5273     ))
  (( .25697    , 11.309    , 2.9060    , 10.929     ))
  (( .20726    , 13.642    , 2.8274    , 13.346     ))
  (( .19865    , 24.860    , 4.9386    , 24.365     ))
  (( .32015    , 32.898    , 10.532    , 31.167     ))
  (( .85789    , 32.931    , 28.251    , 16.921     ))
  (( .19448    , 57.685    , 11.219    , 56.583     ))
  (( .65024    , 316.83    , 206.02    , 240.70     ))
  < .18027E+11>


 NUMERATOR:  DTH/DZP

   .29296E-27  << .28049    >>
  ( .00000     )  ( .00000     )  (-10.621     )  ( 16.590     )
  ( 46.384     )  ( 97.067     )  ( 100.00     )  (-138.57     )
  ( 209.05     )
  (( .44231    , 8.3929    , 3.7123    , 7.5273     ))
  (( .21687    , 11.488    , 2.4913    , 11.214     ))
  (( .98984    , 16.317    , 16.646    , 2.3916     ))
  (( .85130    , 33.163    , 28.232    , 17.400     ))
  (( .20646    , 55.410    , 11.440    , 54.216     ))
  (( .65024    , 316.83    , 206.02    , 240.70     ))
  (( .96657    , 336.66    , 325.41    , 86.321     ))
   .67996E+08>       .37719E-02>

  TRU =123.31   11-Mar-80    11:58
```

Printout of DTH/DZP transfer function

(See **Figure** 9 for **explanation of format**)

```
EXIT
```

Exit BIODYN

D.3 Running PLOT

```
EXE CCPLOT,CCUB,CBODTF
LOADING
EXECUTION

    ENTER TRFN SYSTEM FILE NAME: TAPE20

       M.IMP          11-Mar-80     11:53
        SEMI-SUPINE

       D$$
        C /NZP
        Z1/DZP
       DTH/DZP
```

Execute PLOT

Interactive entry of TF file

Case title

Dump of TF file contents

PLOT execution

```
TAPE20

   M.IMP          11-Mar-80     11:53
    SEMI-SUPINE

                  DTH/DZP
                  D$$
FIRST ORDER DIPOLES CANCELLED :
 46.381000
 100.00000

SECOND-ORDER DIPOLES CANCELLED :
 .14230900      , 8.3929300
 .65024400      , 316.83100
```

Transfer function DTH/DZP

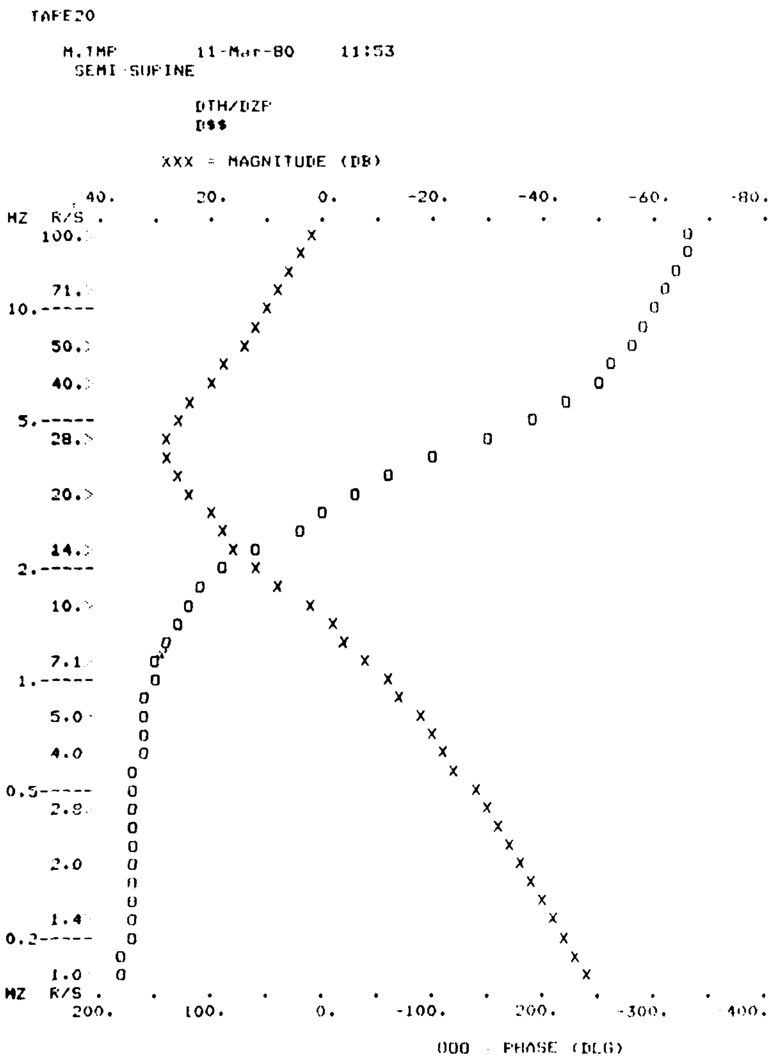
Identical roots in numerator and denominator are cancelled; close pairs are retained

```
NUMERATOR:

 .28049
( .00000      )  ( .00000     )  (-10.621     )  ( 16.590     )
( 97.067      )  (-138.57     )  ( 209.05     )
(( .21687     , 11.488     , 2.4913     , 11.214     ))
(( .98984     , 14.817     , 16.646     , 2.3917     ))
(( .25130     , 33.163     , 28.232     , 17.400     ))
(( .29646     , 55.410     , 11.140     , 54.216     ))
(( .96657     , 336.66     , 325.41     , 86.321     ))

DENOMINATOR:

( 16.091      )  ( 56.079     )  ( 97.512     )  ( 285.86     )
( 353.00      )
(( .25427     , 11.309     , 2.9060     , 10.929     ))
(( .20726     , 13.642     , 2.8274     , 13.346     ))
(( .19865     , 24.860     , 4.9386     , 24.365     ))
(( .32615     , 32.398     , 10.532     , 31.167     ))
(( .85789     , 32.931     , 28.251     , 16.921     ))
(( .17448     , 57.685     , 11.219     , 56.583     ))
   .37219E-02
```

Transfer function to be plotted (see Figure 11 for explanation of format)

(Continued on next page)

D.3 (Continued)



Bode plot of DTH/DZP

XXX is the magnitude curve

Frequencies which are denoted as hertz (HZ) or radians/second (R/s) are exact at ---- and > respectively

000 is the phase curve

(Continued on next page)

D.3 (Concluded)

```
TAPE20
    M.TMP           11-Mar-80       11:53
     SEMI-SUPINE

                    DTH/DZP
                    D$$
```

R/S	DB	DEG
1.00	-48.34	175.9
1.12	-46.31	175.4
1.26	-44.27	174.9
1.41	-42.21	174.3
1.58	-40.15	173.5
1.78	-38.07	172.8
2.00	-35.96	171.9
2.24	-33.83	170.8
2.51	-31.67	169.7
2.82	-29.46	168.4
3.16	-27.20	167.0
3.55	-24.88	165.3
3.98	-22.48	163.4
4.47	-19.97	161.2
5.01	-17.34	158.6
5.62	-14.56	155.5
6.31	-11.58	151.7
7.08	-8.38	147.1
7.94	-4.91	141.1
8.91	-1.17	133.2
10.00	2.85	122.9
11.22	7.30	110.0
12.59	12.34	89.2
14.13	16.45	56.6
15.85	18.74	24.4
17.78	20.72	-1.7
19.95	23.31	-27.3
22.39	26.34	-60.1
25.12	28.34	-104.6
28.18	27.92	-150.8
31.62	26.04	-189.7
35.48	23.40	-221.9
39.81	20.28	-246.8
44.67	17.12	-264.3
50.12	14.43	-275.8
56.23	12.60	-285.8
63.10	10.82	-299.4
70.79	8.59	-311.4
79.43	6.37	-320.3
89.13	4.35	-327.3
100.00	2.51	-333.2

```
EXIT

4
```

Listing of frequency (rad/sec), amplitude (dB) and phase (deg) at 20 evenly-spaced increments per decade for DTH/DZP

(This listing is only generated if XL = 1.0 in the CHOICES file for this transfer function)

Exit PLOT

APPENDIX E

INTERCOM EXAMPLE PROBLEM

This appendix presents a typical terminal session in the Intercom 4.7 operating system, accessing the CSA mainframe at Wright-Patterson AFB´s ASD Computer Center. The dialog is annotated so that a typical user will easily understand the basic sequences of parameter entry and job steps. All user responses are underlined; each is terminated by a carriage return.

This particular session was an exercise using a 9 cm viewing distance and the standard crewman (STDCRW) parameter set. It was one of a series of runs which attempted to determine optimal display distance for minimizing image motion of a vertically vibrating crewman. The example is carried far enough for the potential user to see how the programs interface with INTERCOM job control and file management commands.

The steps followed in the investigation are listed below:

1) Log in to Intercom.
2) Attach the PARAMETER file to be modified and name it TAPE20.
3) Attach the CREATE program, called EXECRT.
4) Run EXECRT, make changes to existing file, assemble new CHOICES file.
5) Assemble batch job to run BIODYN and PLOT, using the two PARAMETER file (old and modified) and the new CHOICES file.
6) Submit batch job to input queue.
7) When job completed, list the output file.

The user is advised to retain in his permanent files only those which he wishes to use in the future, and to frequently purge his directory of unneeded parameter and output files in order to forestall job failures resulting from file space overload.

Typical INTERCOM Terminal Session

user responses underlined

```
ASD COMPUTER CENTER INTERCOM 5.0
SYSTEM CSA
DATE 05/20/80        TIME  14.46.39.                    1. Log in to INTERCOM

PLEASE LOGIN

ENTER 3-DIGIT TERMINAL ID-

05/20/80    LOGGED IN AT  14.46.52.
            WITH USER-ID CK
            EQUIP/PORT 12/001

COMMAND- REQUEST,TAPE7,*PF

COMMAND- REQUEST,TAPE8,*PF                              2. Attach files to I/O units

COMMAND- ATTACH,TAPE20,STDCRW

 PF CYCLE NO. = 001

COMMAND- ATTACH,EXECRT

 PFN IS                                                 3. Attach EXECRT(CREATE) program file
 EXECRT
 PF CYCLE NO. = 001
COMMAND- EXECRT }---- 4. Execute EXECRT program module
    NEW FILE ?  }---- 5. Select existing data file (STDCRW)
NO
    LISTING DESIRED? }- 6. List data file
YE
    (LO)NG OR (SH)ORT LISTING? }------- 7. Program rejects unrecognizable input
LI
    (LO)NG OR (SH)ORT LISTING? }------- 8. Long listing option selected
LO
    NEW CHOICES FILE ?         }------- 9. Affirmative on CHOICES option
YE
    BIODYN TFS DESIRED FOR PIVIB ? }--- 10. Negative on PIVIB option
NO
    TRANSFER FUNCTION INPUT :
    FIRST LINE-RESPONSE MNEMONIC, FORCING FUNCTION MNEMONIC
       (AAA,AAA) ; ENTER XXX TO STOP
    SECOND LINE-PLOTTING INFORMATION, 5 ITEMS :
       BODE LOWER FREQ. LIMIT
       BODE UPPER FREQ. LIMIT
       BODE UPPER PHASE LIMIT (0. DEFAULTS TO 200.)
       BODE LOWER PHASE LIMIT (0. DEFAULTS TO -400.)
       LIST (1. TO LIST TABLE, 0. FOR NO LIST)
    IF NO PLOT DESIRED, ENTER 0. FOR ALL ITEMS
RHF,DZF
    RHF NOT PERMISSIBLE, PLEASE REINPUT }- 11. Illegal parameter selected
RHD,DZF
.1,200.,0.,0.,1. }--------------------- 12. Program screens for out-of-limit values
    MAX FREQUENCY RANGE IS 3 DECADES
    PLEASE REINPUT ENTIRE LINE
1.,100.,0.,0.,1. }--------------------- 13. Finally, valid input
XXX }---------- 14. Exit from CREATE
     STOP
       .222 CP SECONDS EXECUTION TIME
*
```

Session continues with batch run

Sample INTERCOM Batch run

```
COMMAND- EDITOR
```

1. Invoke INTERCOM editor

```
..CREATE,S

ENTER LINES
SAR,CM150000,STCSA.  L800015,RIEDEL,(213)679-2281
ATTACH,TAPE7,CHOICE1.
ATTACH,TAPE8,VIEW9.
ATTACH,EXERIO.
ATTACH,EXEPLT.
EXERIO(TAPE4,OUTPUT,TAPE7,TAPE8,TAPE19,TAPE21).
REWIND,TAPE19.
EXEPLT(OUTPUT,TAPE19).
*EOR
=
```

2. Create batch job stream

```
..SAVE,GOFILE,NOSEQ

..STORE,GOFILE,L800015

 CT ID=  L800015 PFN=GOFILE
 CT CY= 001   00000128 WORDS.:
..END
```

3. Preserve file containing job stream

```
COMMAND-  BATCH,GOFILE,INPUT,HERE
```

4. Batch job stream to input queue

```
COMMAND- FILES

--LOCAL FILES--
 *EXECRT   *GOFILE   $INPUT    $OUTPUT   *TAPE7
 *TAPE8    *TAPE20
--REMOTE EXECUTING JOBS--
  SARCK02
COMMAND-
TASK "\..TEL" TERMINATED
TASK EXIT WITH OUTSTANDING IO
  FC=106646
  FS=170000
  RO=003770
```

5. Job terminated by system crash

Note: Output files generated by BIODYN, when listed, are identical in format to printouts shown in Appendix D.

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